SMITHSONIAN ASTROPHYSICAL OBSERVATORY

Submillimeter-Wavelength Telescope Array

Feasiblity Study of Reflector

MEMO #19

prepared by
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CONTENT

1. Introduction and Overview

The goal of the study is the preparation of facts as basis for a trade off study to evaluate the optimum design for the Smithsonian Astrophysical Observatory (SAO) Submillimeter-wavelength Telescope Array.

The main evaluation criteria will be:

- diameter of telescopes
- type of back-up structure
- panel type, size and material
- panel surface
- costs

To prepare all the facts and collect the available data of the modern millimeter and submillimeter telescopes the work packages given in the proposal for this study were used. During the study preparation logic reasons led to the structuring of this paper. But all work packages can be found as given on the next page.

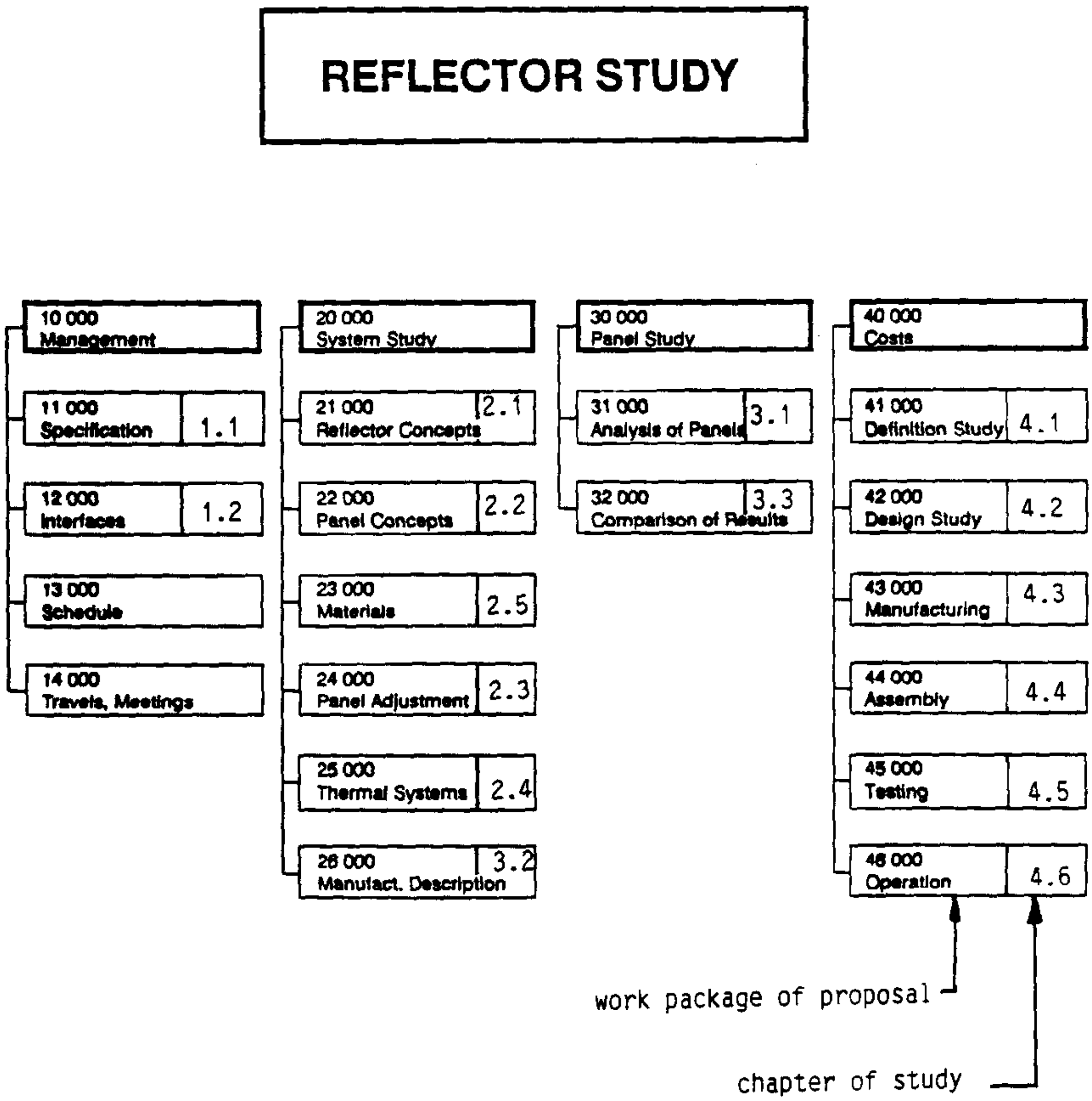
Most of the experiences documented in this paper have been elaborated during the design and manufacturing of the latest and advanced millimeter telescopes

- 32 m - Pico Veleta
- 15 m - IRAM-array
- 10 m - SMT

All ove them have been erected with major contribution and system responsiblity for the reflector by MAN companies

MAN-GHH-MAN Gutehoffnungshütte AG
Dept. ISA and ISK
and
MAN Technologie AG
Dept. RL/Lightweight Structures.

WORK PACKAGE DESCRIPTION AND CHAPTERS



1.1 Specification

The basic specification was given by SAO. Missing values have been completed by MAN.

GENERAL LOADCASES	
· temperature - 20°C to + 30°C	
· survival temperature + 45°C	
· temperature	gradient across structure 5°C through the structure 5°C
· temperature gradient 5°C per hour	
· Wind loads	
- operation	20 m/s (46 mph = 72 km/h)
- survival	56 m/s (129 mph = 202 km/h)
- limiting wind for transport	16 m/s (36 mph = 58 km/h)

GENERAL OPTICS	
· Focal ratio	0,35 for primary 8 to 15 total

All loadcases are logical and in the same range as for standard radiotelescopes.

The limiting wind speed for transport seems low. Experience with IRAM telescope shows, that all structural parts should be designed app. 30 m/s (47 mph = 118 km/h). This gives a safety factor at emergency cases.

REFLECTOR SPECIFICATIONS

COMPARISON OF RMS-VALUES (μm)

	IRAM	SMT	SAO
Wind, Gravity	25	9,5	8
Temperature	25	10	10
Panels	25	10	10
Adjustments	40	10	8
TOTAL	**50**	**17**	**15**

The comparison shows, that all specified values are realistic and with future development some improvements are possible to build outstanding submillimeter telescopes for the next generation and to reach the new goals.

The major possibilities therefore are given in

- panel accuracy and
- adjustment.

Especially adjustment and measurement of reflector accuracy can be improved compared with the state of the art.

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SPECIAL LOADCASES FOR PANELS:

- surface error (deviation from ideal paraboloid) 15 μm rms
- surface error distribution:
  - form error 3 μm rms
  - replica error 5 μm rms
- mechanical deformations 3 μm rms
  - gravity and wind loads up to 14 m/sec ± 6 m/sec
- thermal deformations 4 μm rms
  - 0° C to + 30° C temperature range
  - during daytime sunshine transient with 0 to 200 W/m² evecitvely absorbed radiation and nighttime cooling towards the sky
  - max. thermal gradient for Cfk-panels at 30 °C :1,5 °C
- measurement error and contingency 2 μm rms
- reflectivity for wavelength between 0,5 and 5 mm 97 %
  - max. ratio of IR. emissivity at 300° K to sunlight
  - absorptivity in surface coating
  - panel setting 10 μm rms (8 goal)

Definition of error:

Form + Replica + Measurement = 10 μm rms (7 goal)

$$\sqrt{\text{mech.}^2 + \text{therm.}^2} = 5\ \mu\text{m (3 goal)}$$

All this values can be achieved for optimum operation at submillimeter wavelength. But detailed development has to be done to fulfill all combined specified values.

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PANEL-SPECIFICATIONS

COMPARISON OF RMS-VALUES (μm)

	IRAM	SMT	SAO
wind load	not specified	2/12 m/s	2/20 m/s
Δ t absolut		3/20° C	4/40° C
Δ t panel		6/2,5° C	4/1,5 ° C
Elevation 0° Elevation 90 °		2 2	1,5 1,5
Total	15	7	6
Manufacturing	20	9 goal 7	5

All specified values will be achieved, what has been shown by the IRAM and SMT results The most critical requirements are the thermal loadcases.

The manufacturing can be improved, what latest results at MAN have shown.Cfrp-panels have been made for the balloon-telescope PRONAOS with an accuracy of 2,4 μm rms. The panel size was similar to that of SAO.

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.2 Interfaces

Interfaces have to defined between reflector and reflector mount. According to the MAN-GHH study

- direct connections to

central hub or the yoke are possible.

Clear interfaces can be given with an direct connection to the central hub with an isostatic mount system similar to the

- CALTEC telescopes or of the
- IRAM telescopes

A more detailed study must elaborate the design of interfaces to a yoke.

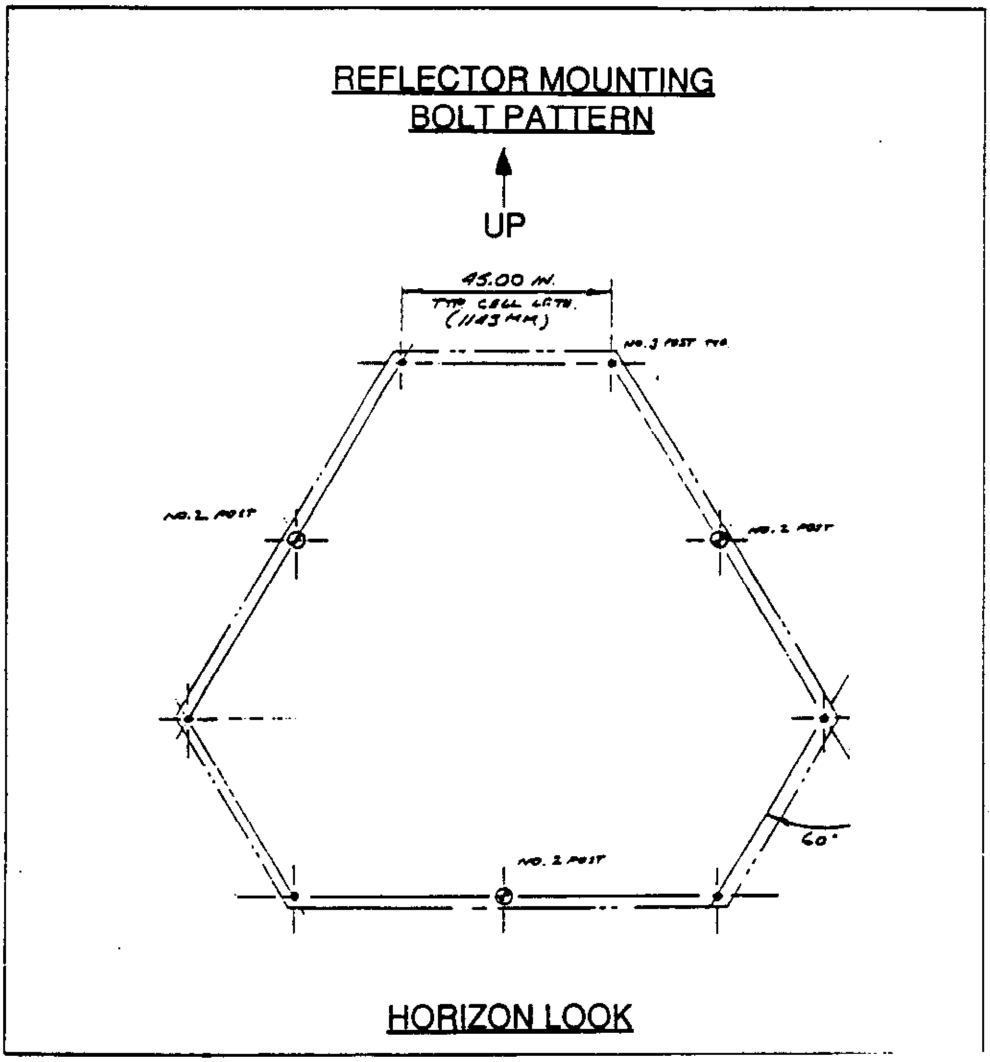

Fig. 1.1

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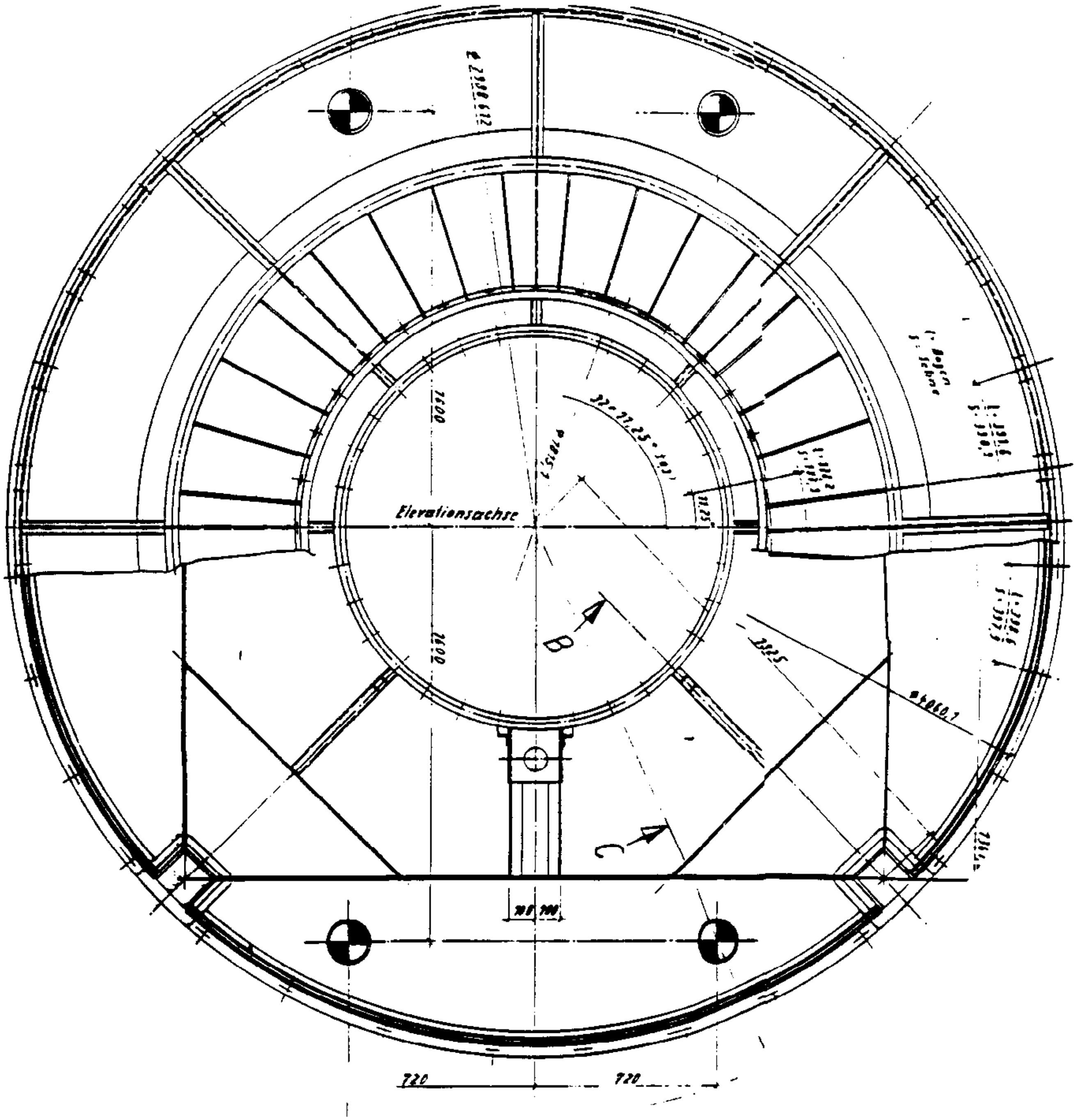


Interface points

Fig. 1.2 Interface IRAM Central Hub

2. Reflector Systems Study

This chapter shows the latest designs of millimeter and submillimeter reflectors and the possibilities for the SAO array.

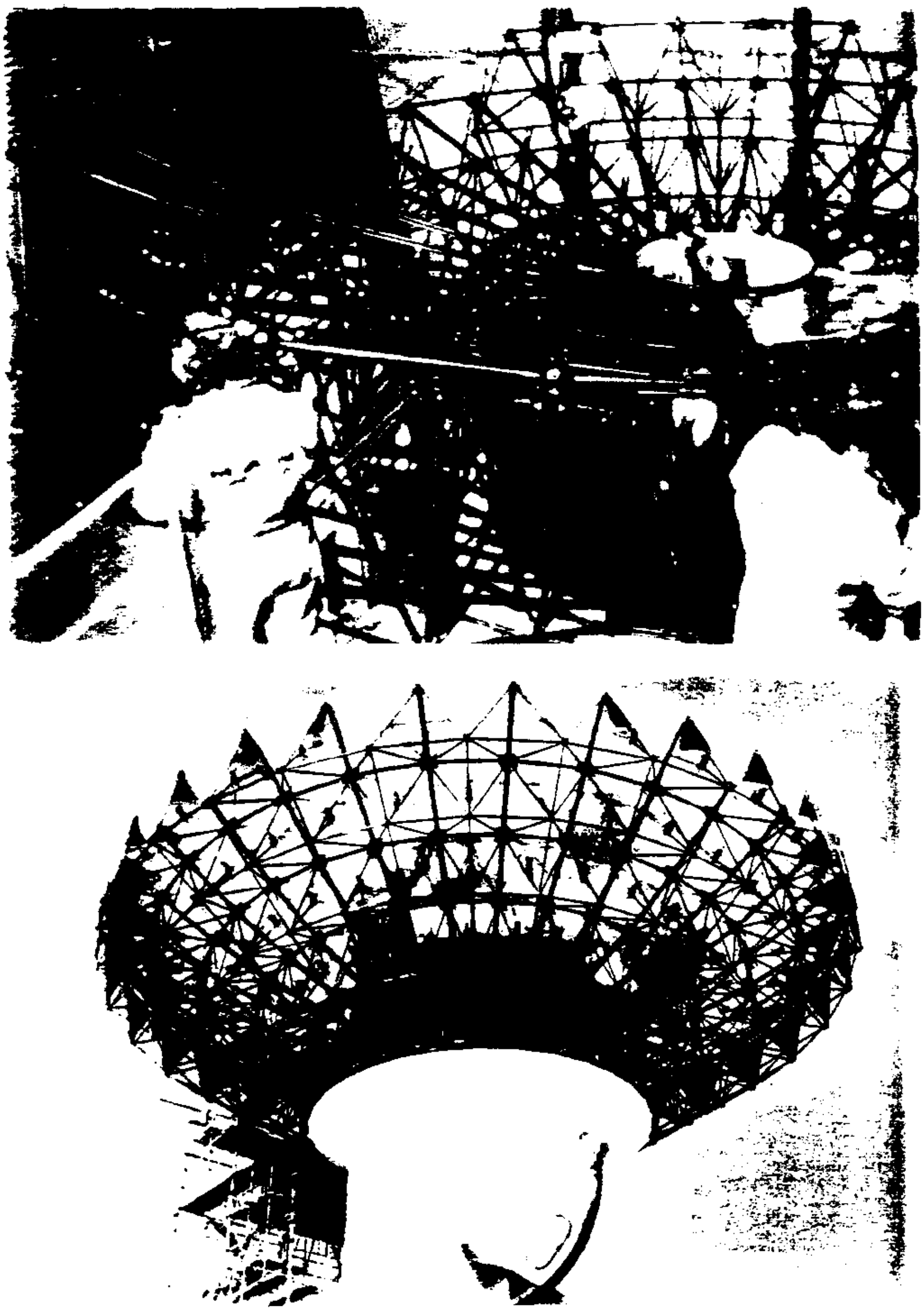
2.1 Reflector Concept

Figures 2.1 and 2.2 present the Radiotelescope Structures of the 15 m-IRAM and 10 m-SMT Telescopes.

The IRAM dishes are made with upper and lower girders of Cfrp. Central hub and diagonal struts are made of steel to achieve a homogeneous thermal behaviour. The connections are specially casted hollow steel nodes.

All SMT struts are made of Crfp by filament winding. They are connected by invar fittings and solid invar nodes.

WITH CARBON FIBER REINFORCED STRUTS



RADIOTELESCOPE FOR MILLIMETER WAVELENGTH

15 m Diameter

Trusswork with
348 nodes of
10 types
1152 cfrp struts

Customer
IRAM Grenoble

Reflector
accuracy 80 µm

Delivered Items: 4

P. 6654-26 8060-86 PAMB4

Fig. 2.1

STRUCTURES

SMT DESIGNED BY KRUPP

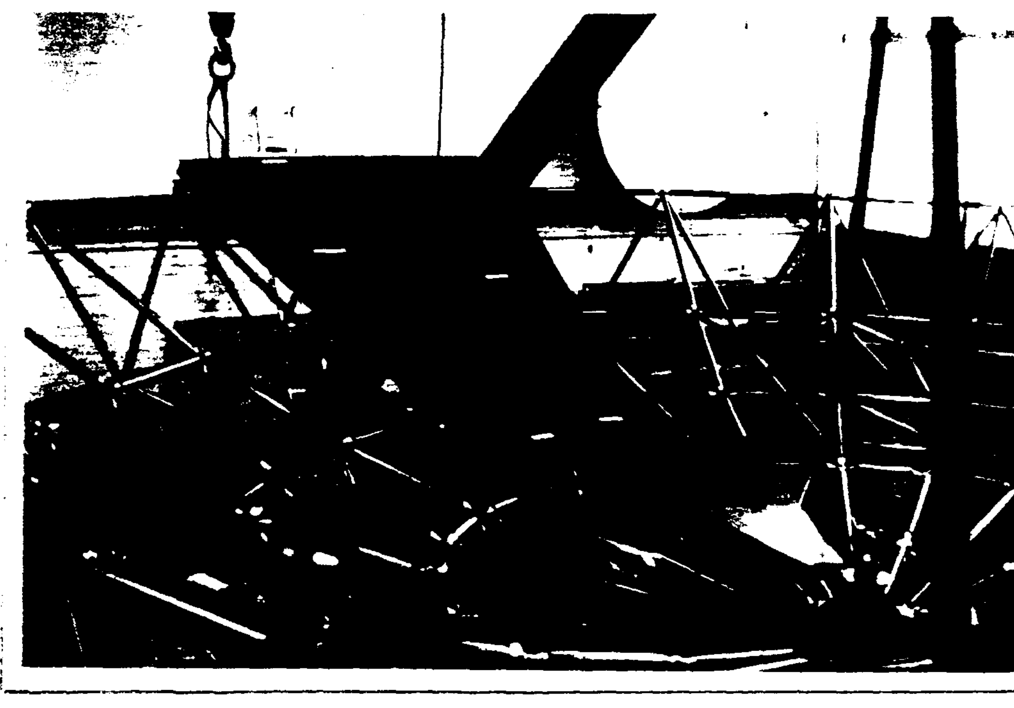


Fig. 2.2

Figure 2.3 shows the basic design of a 6 m-reflector which has a 22,5° segmentation-angle in two rings.

This design leads to 32 panels in 2 rings.

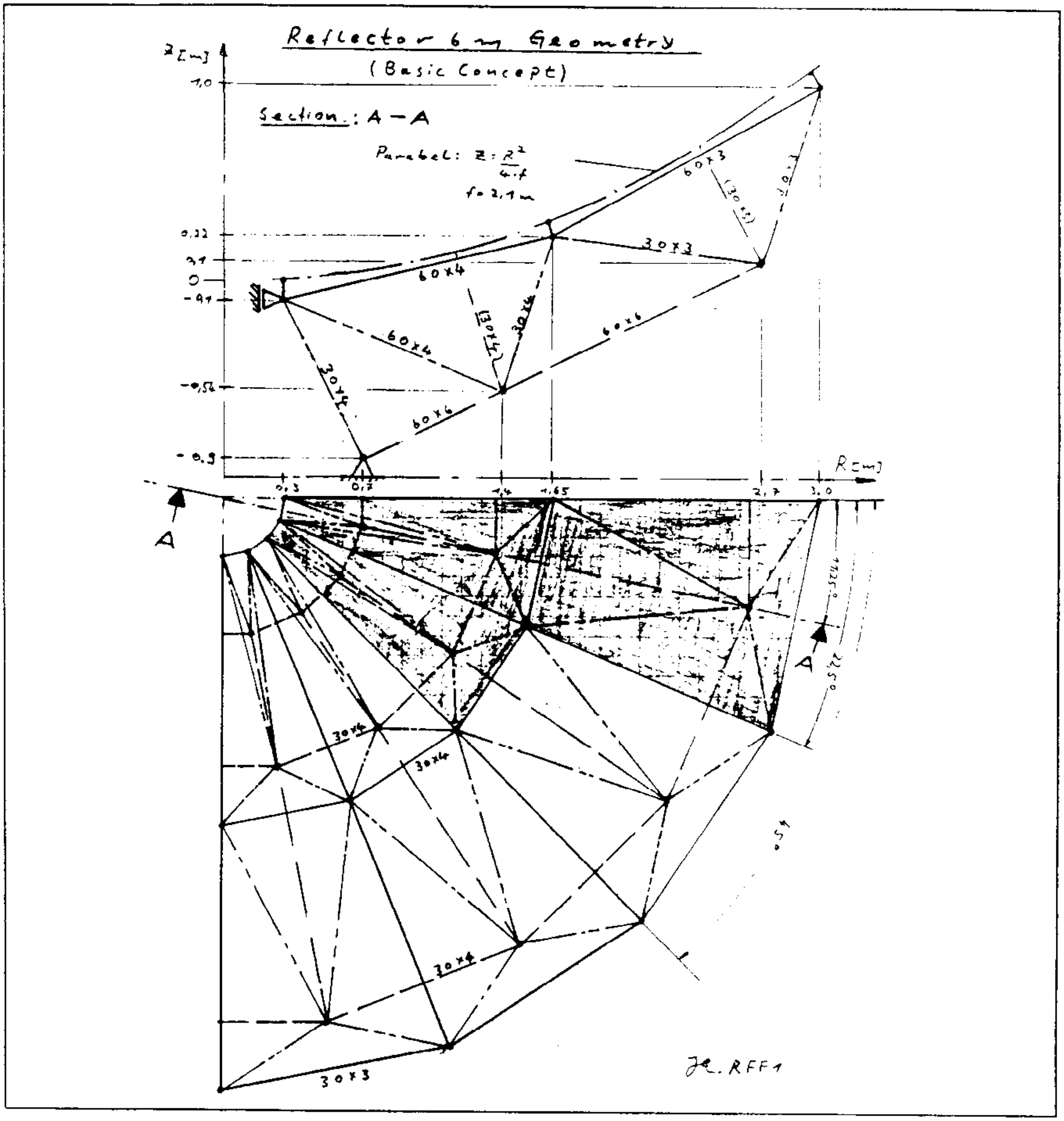


Fig. 2.3 SAO basic concept

Figure 2.4 presents three possible designs of a high precision reflector:

- standard trusswork
- boxbeam (shell structure with separate panels)
- integrated boxbeam (shell structure, where panels are part of the structure)

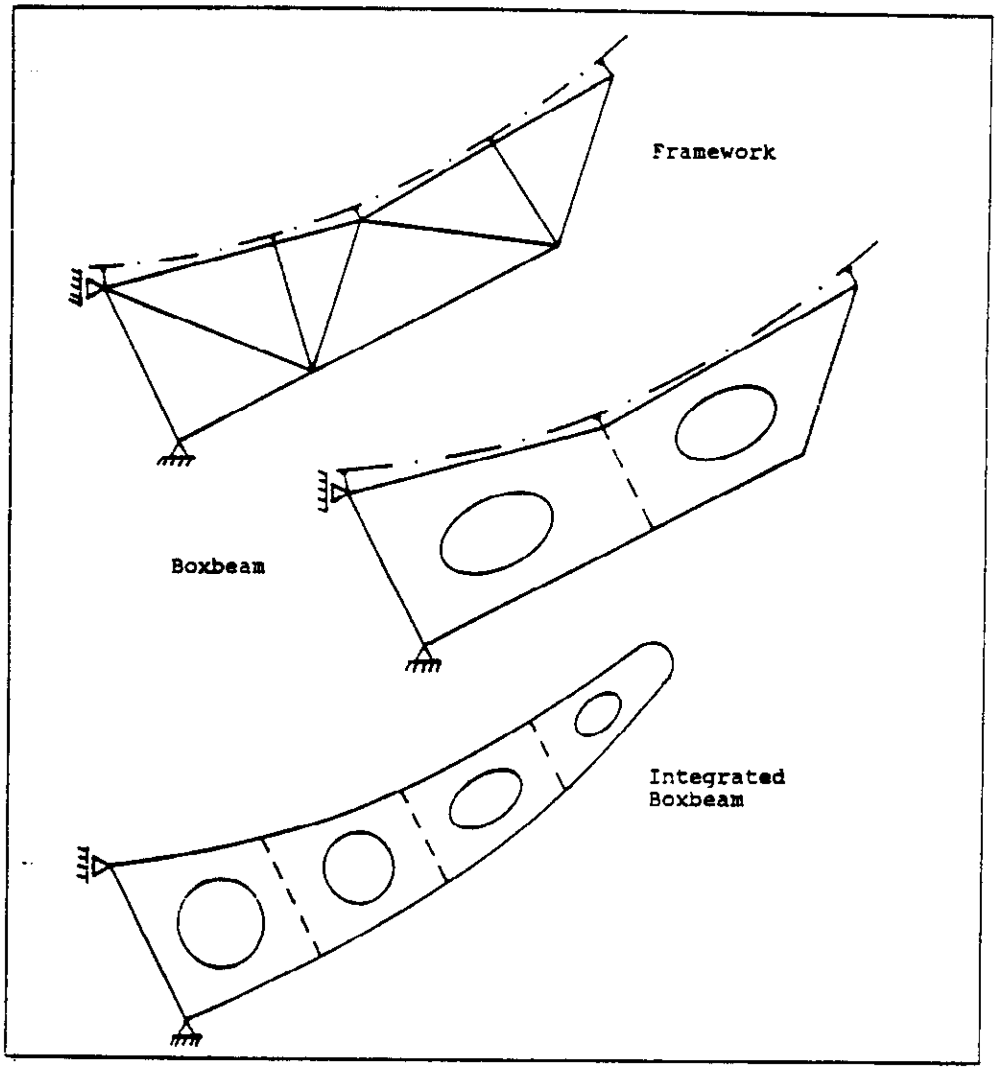


Fig. 2.4 Structure concepts

2.1.1 Trusswork structure (Fig. 2.3):

For the frame work design the panels are attached to the trusswork on adjustable attachments. A four or five point attachment can be foreseen.

Usually short invar struts are used, which are mounted on the nodal points of the upper frame.

The attachment of the fifth point will be realized by a rod connected to a nodal point of the lower frame, (see Fig. 2.3, rod 30 x 30 and 30 x 4).

This solution was chosen for the outer ring of the 10 m-SMT-Telescope and for the 15 m-IRAM-Telescope.

In the IRAM-Telescope are installed actuator fixations in order to adjust the panels by computer aided wire-remote control.

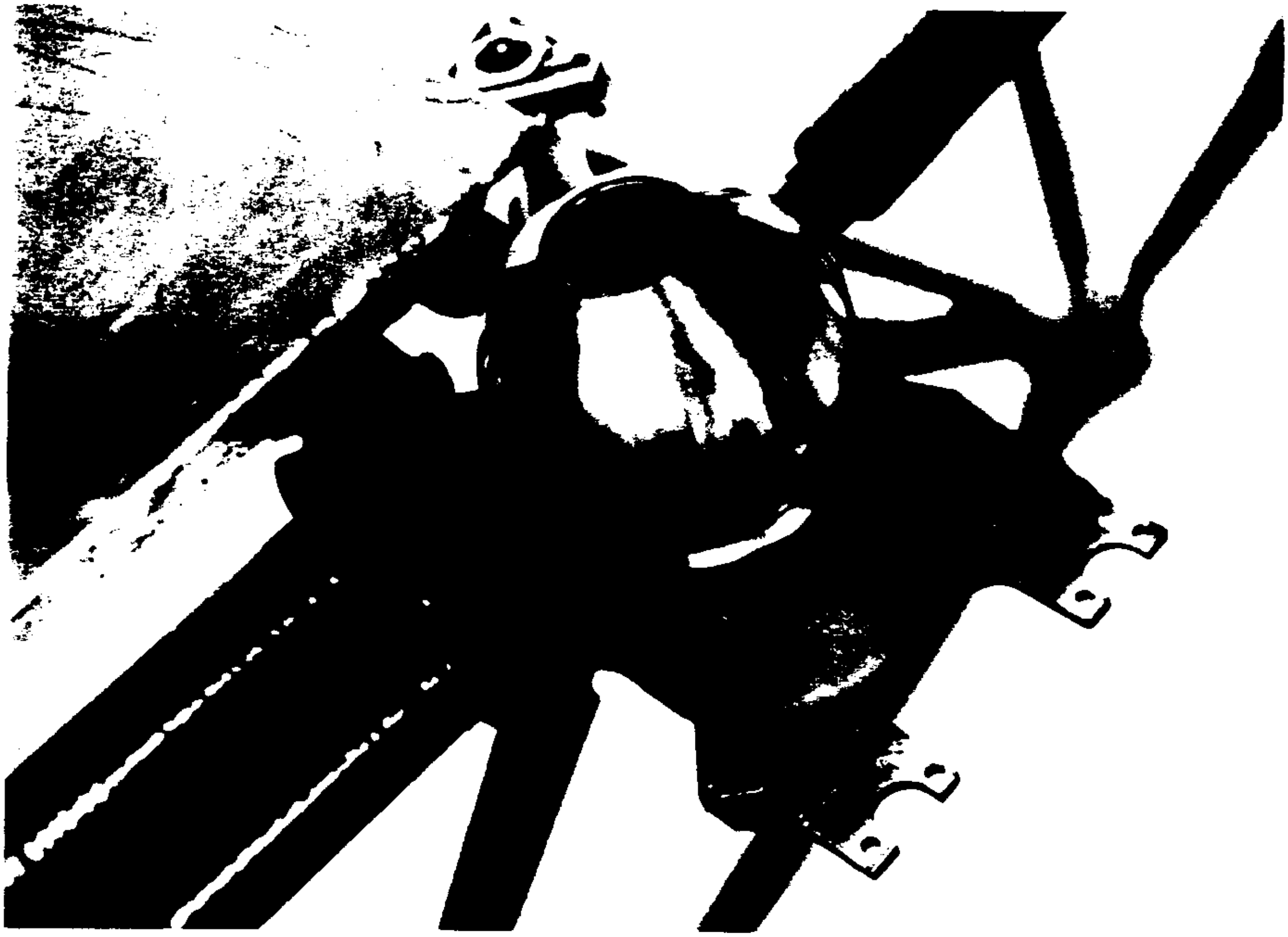
The rolloff-shed-design requires a covering of the rear side of the trusswork.

A tubular trusswork in Cfrp needs metal fittings for the tube ends and metal nodes for the rod connections. For a thermally stable, high precision telescope design these metal parts have to be made of invar material (steel-nickel-alloy, CTE 1,5 ppm). Highly time-intensive manufacuture and adjustment must be expected for this solution.

Figures 2.5 and 2.6 show the steel nodes of the IRAM Telescope.

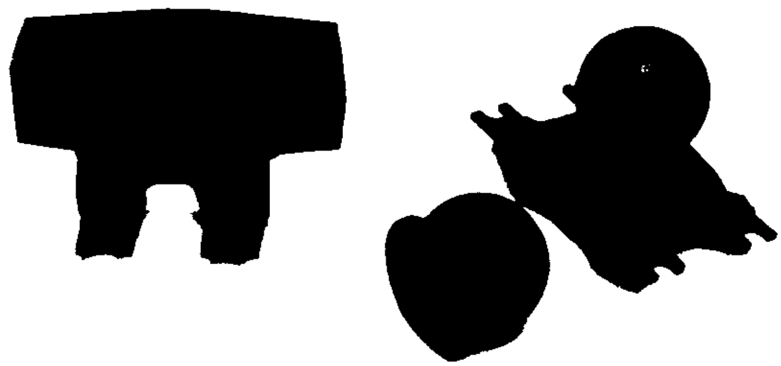
An other framework design can be realized by the use of beams with open cross sections, like L-, L-, or [- beams. The feature of this concept are planar nodal plates for rod connections which can also be made of Cfrp-material (see Fig. 2.7).

Already structural members for such a design have been made at MAN for space applications (see Fig. 2.9).



DETAILFRONT NODE
DIAMETER 110mm
TOLERANCE + 0,1 mm
MASS 4700 g

Fig. 2.5



STRUCTURAL
STEEL NODES

QUADRUPOD
NODE

FRONT SIDE
WITH ACTUATOR
FIXATION

REARSIDE

FRONT NODE
DURING ASSY

Fig. 2.6

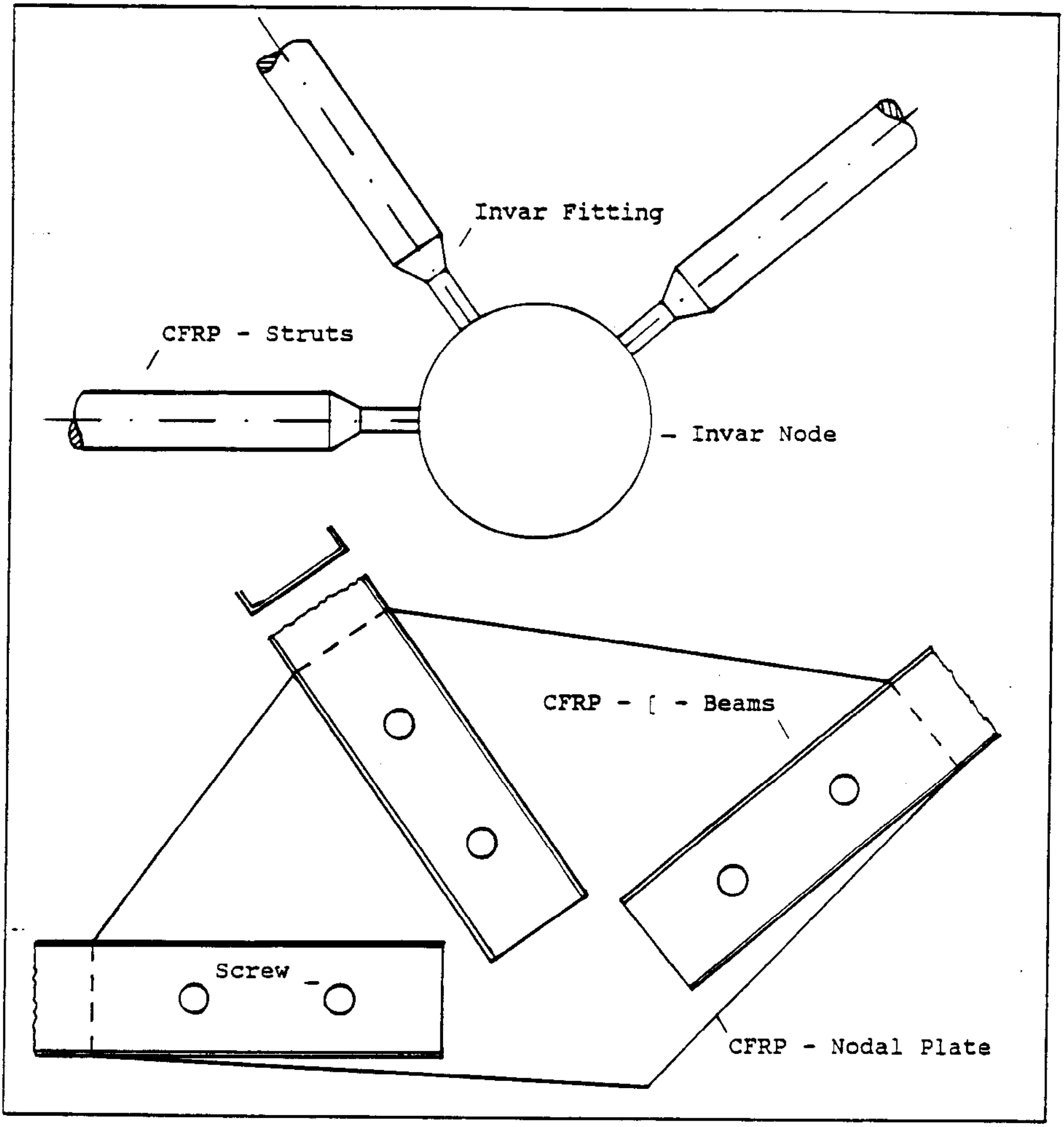


Fig. 2.7 Strut connections

Length	4980	mm
Height	700	mm
Mass	45	kg
Com-pression	100	kN
Bending	180	kNm

CFRP-TECHNOLOGY
Bonded and riveted trusswork

Fig. 2.9

2.1.2 Shell structure

BOXBEAM-DESIGN (Fig. 2.4b):

This design concept is based on a closed box instead of truss framework for the backup structure of the dish.

The box is thus a closed shell structure assembled of Cfrp sandwich plates.

The box elements will be assembled together to form a cosed dish.

The covering of the rear side of the dish is integrated in the structure.

Investigations concerning stiffness and adjustment of the attachments between the box elements are necessary.

INTEGRAL-BOXBEAM

This design is similar to the boxbeam solution (Fig. 2.4 b), but here the reflector panel is integrated to the upper shell of the boxbeam. A disadvantage of this solution is the unadjustable positioning of the reflecting panel over the box. Fig. 2.10 shows the reflector assembled of boxbeam segments, which are arranged like cake pieces.

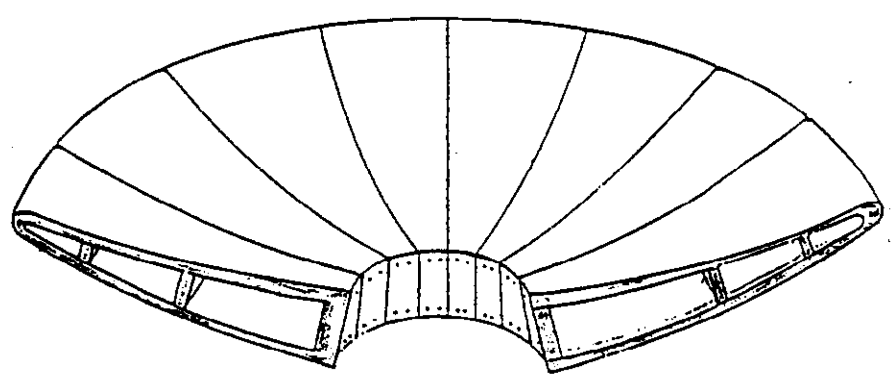


Fig. 2.10 Integral boxbeam

2.1.3 Technical Data

2.1.3 Mass estimations

- mass evaluation of the basic design:

The following table shows the mass estimation for a 22,5°-segmentation angle of the basic trusswork concept shown in Fig. 2.3:

Cfrp-struts size [mm]	mass/meter [kg]	length [m]	mass [kg]	mass-percentage [%]
30*4	0.52	6.0	3.1	
30*3	0.47	5.6	2.7	
60*6	1.63	2.2	4.1	
60*4	1.12	5.2	5.7	
60*3	0.86	3.2	2.8	
		total	18.4	20
invar fittings	mass [kg]	quantity	mass [kg]	
diameter 30 mm	0.4	30	12	
diameter 60 mm	1.2	12	24	
		total	36	39
invar nodes				
diameter 90 mm	3.0	6	18	19
		total	54	58
inner panel			5	
outer panel			15	
		total	20	22
total mass of a 22.5°-segment			92.4	100
total mass of the dish			ca. 1.500	

Table 2.1.1: Mass evaluation for a 6 m-trusswork reflector segment

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This example shows a high mass fraction of metal fittings and nodes.

A trusswork design which enables integration of the rod connections in the Cfrp-structure has advantages in mass saving. The beam design with open cross sections for the rods, as described before, provides a practical solution.

Fig. 2.9 shows a [- Beam structure developed for the ARIANE 5 Thrustframe.

The following mass budget for a beam-trusswork design can be evaluated to:

beams	25 kg
nodal plates	5 kg
inner panel	5 kg
outer panel	15 kg
total mass of a 22.5°-segment	50 kg
total mass of the dish	800 kg

Table 2.1.2: Mass budget of a beam-trusswork design

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Mass estimates for the shell designs:

The following table 2.1.3 shows a mass estimate for the shell design as closed boxbeam with separately mounted, or structurally integrated reflector panels.

	BOXBEAM			INTEGRAL-BOXBEAM		
structual part	area weight [kg/sqm]	area [sqm]	mass [kg]	area weight [kg/sqm]	area [sqm]	mass [kg]
bottom-plate	5	2.4	12	5	2.4	12
side-plates	5	4	20	5	4	20
rib-plate	5	.36	2	5	.36	2
top-plate	5	2	10	10	2	20
panels	10	2	20	(integrated as top-plate)		
attachments between the segments			10			10
total mass			74			64
total mass of the dish			ca. 1200			1000

Table 2.1.3: Mass estimation for a 22.5 -segment in boxbeam or integral boxbeam design

A mass comparison between the basic design and the boxbeam design shows that a roughly 25 % mass reduction in the boxbeam design seems to be possible.

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2.1.3.2 Performance of the design concepts

Based on the specifications of chapter 1.1 and the material data of chapter 2.3 the following comparative evaluations were made.

Supported by computer calculation, the deformation of the reflector parallel to the focus axis for two thermal and two mechanical load cases was analysed.

Figures 2.11,12 present the deformation of the reflector parallel to the focus axis for two thermal and two mechanical load cases.

For each design concept in these Figures a different load case gives the maximum deformation.

For the integral boxbeam in Cfrp-HM, the thermal deformation is reduced by a factor of four compared with the Cfrp-HT integral boxbeam. This is due to in the lower CTE of the Cfrp-HM material.

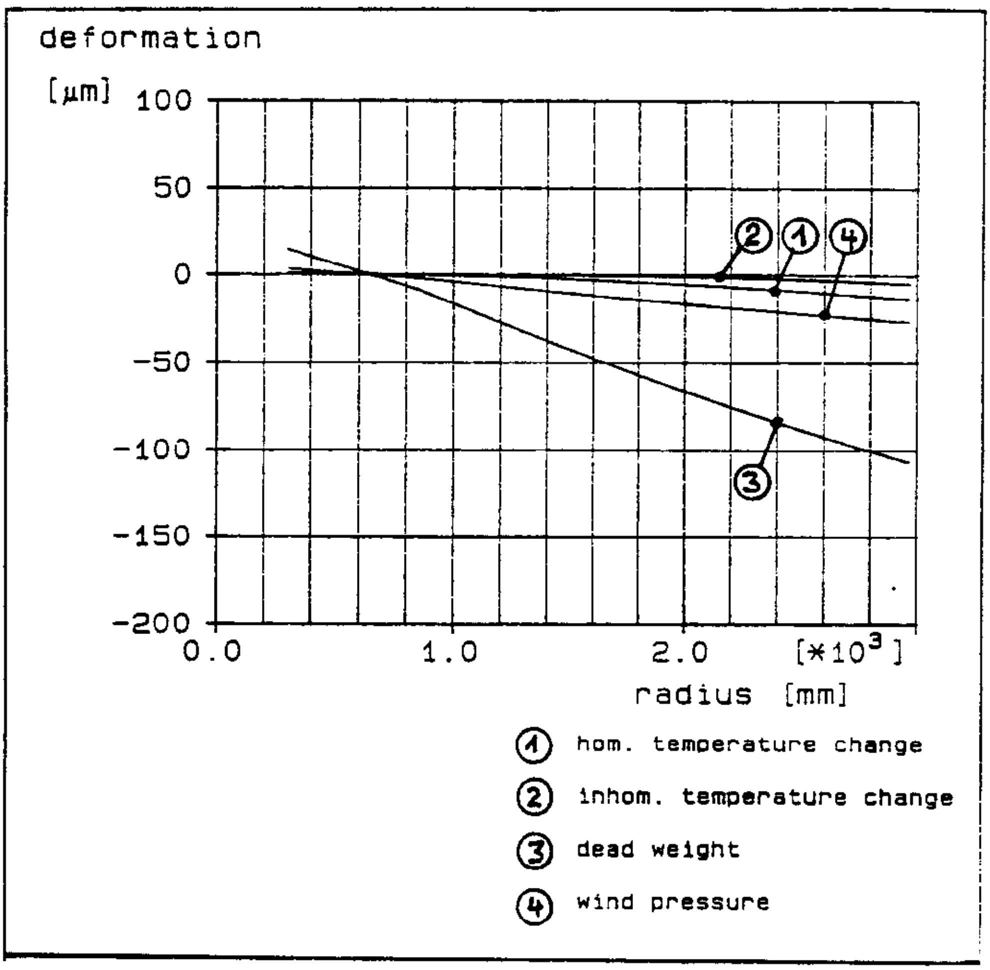

Fig. 2.10 Deformation of frame work HT

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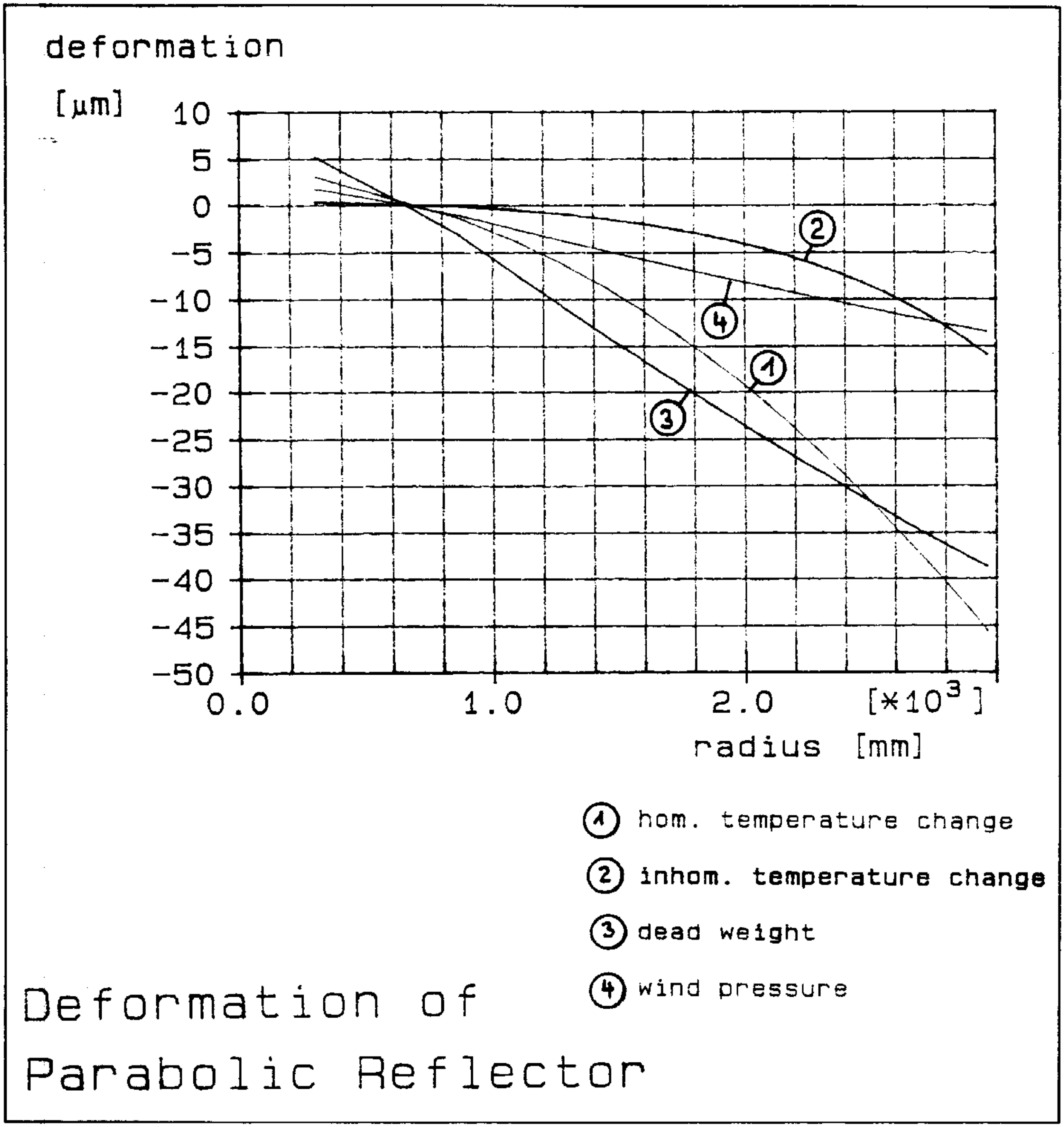

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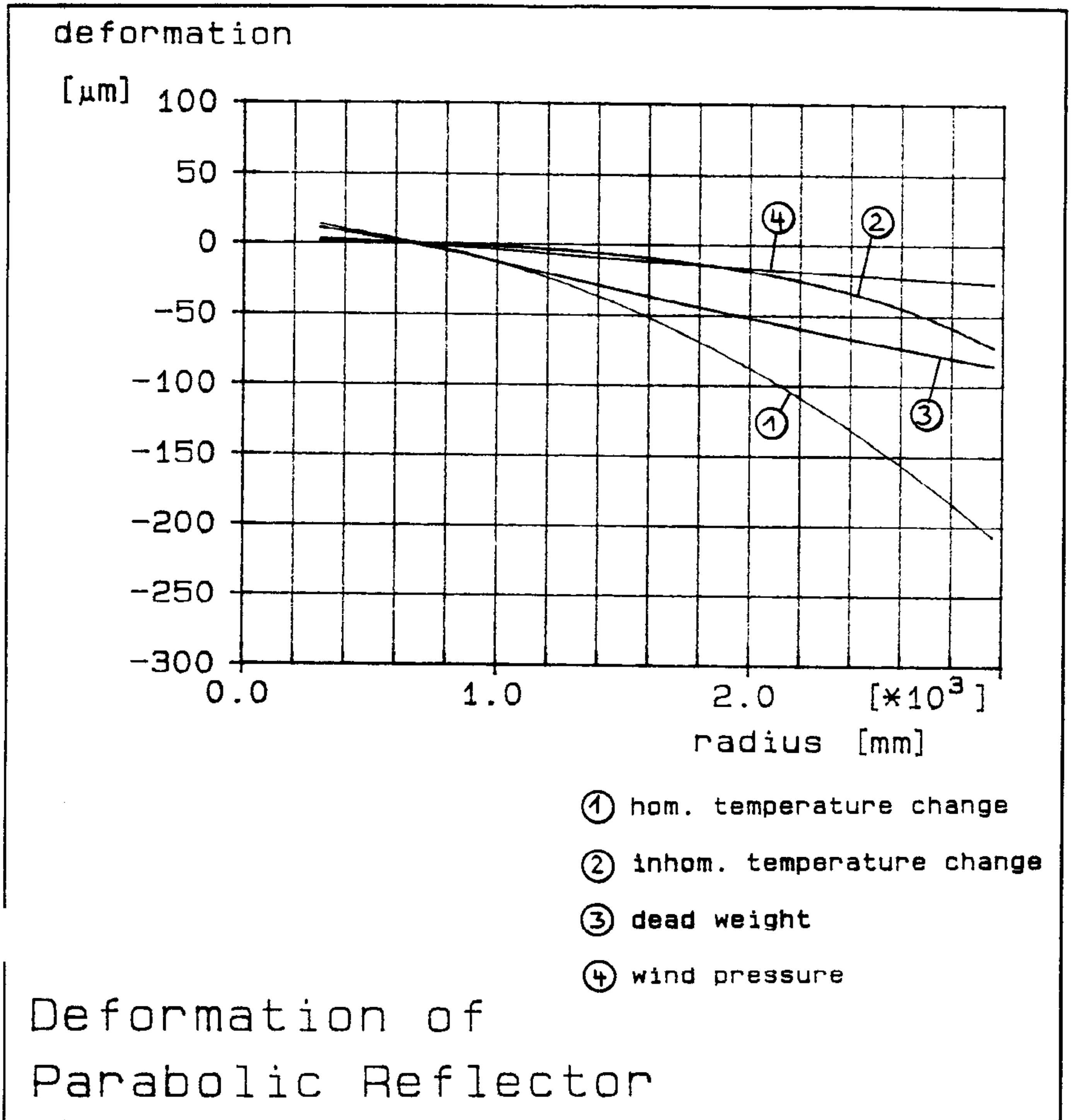
Fig. 2.11 Deformation of integral boxbeam HM



RL, 04/90 - vo

Fig. 2.12 Deformation of integral boxbeam HT

The following Table 2.1.4 gives an overview of the calculated maximum deflection of the dish for the different design concepts.

Design Concept:	TUSSWORK			BOXBEAM	INTEGRAL BOXBEAM	
	tubular		rectangular			
Cfrp-fiber	HT	IM	HT	HT	HT	HM
mass [kg]	1500	1550	800	1200	1000	1050
max. def. [microns]:						
hom temp 70	14	14	14	207	207	46
trans. temp 5	5	5	5	72	72	16
wind 10 m/s	33	26	33	28	27	16
lg-zenith	126	102	73	84	85	39
lg-horiz.-zenith	76	61	44	50	51	23

Table 2.1.4: Comparision of the maximum deflecion for different designs.

For this comparative investigation no best fit calculations were made.

The following two Figures 2.13 and 2.14 present the maximum deflection versus-mass and diameter for a Cfrp-IM tubular framework design.

The increase in mass is caused by a change of the diameter of the tubes.

For example, in the case of the main frame the diameter was shifted from 60 mm up to 120 mm

Most influenced are the mechanical deflections (wind- and g-load).

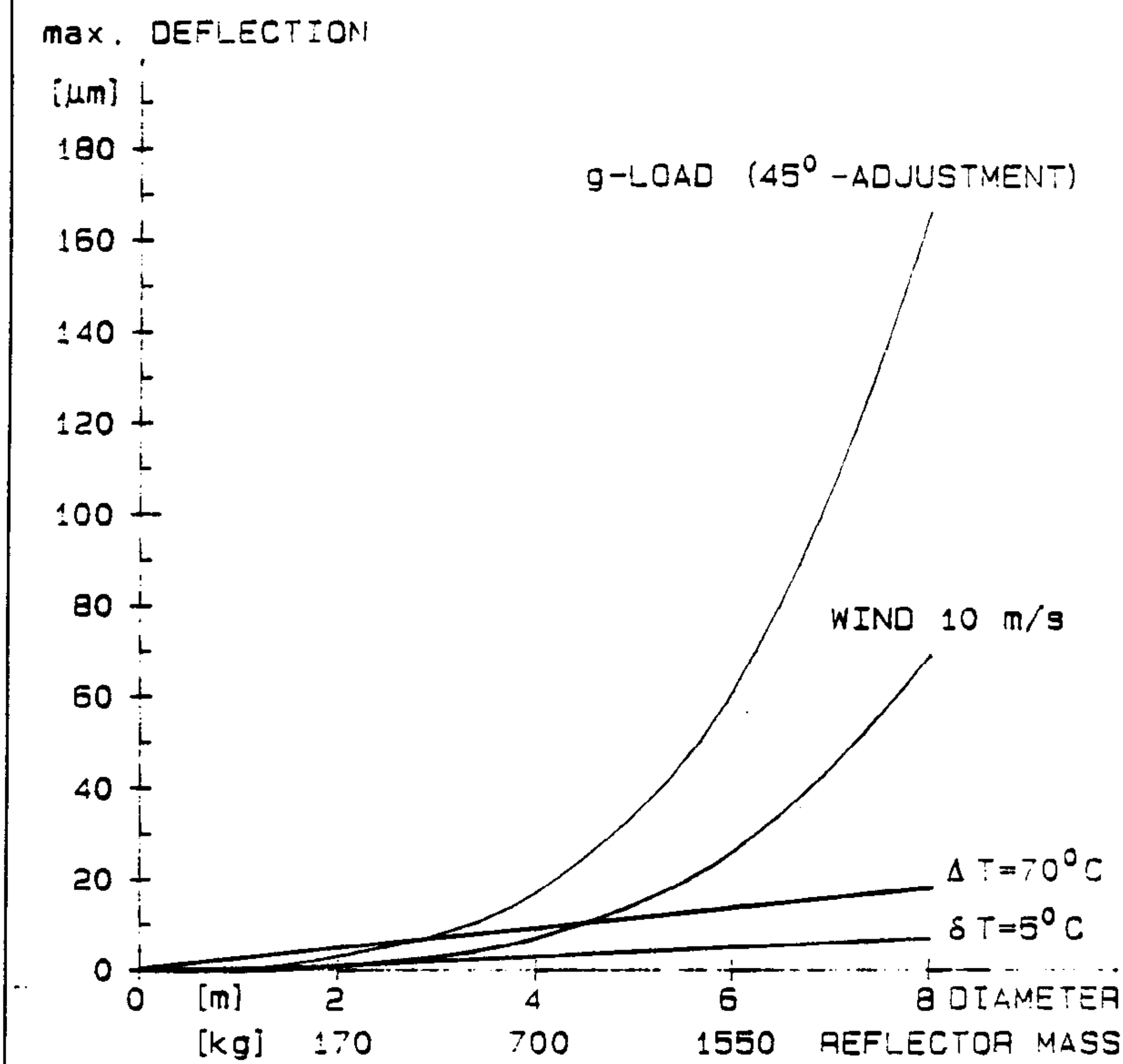


Fig. 2.13 MAXIMUM DEFLECTIONS VERSUS DIAMETER TRUSSWORK TUBULAR

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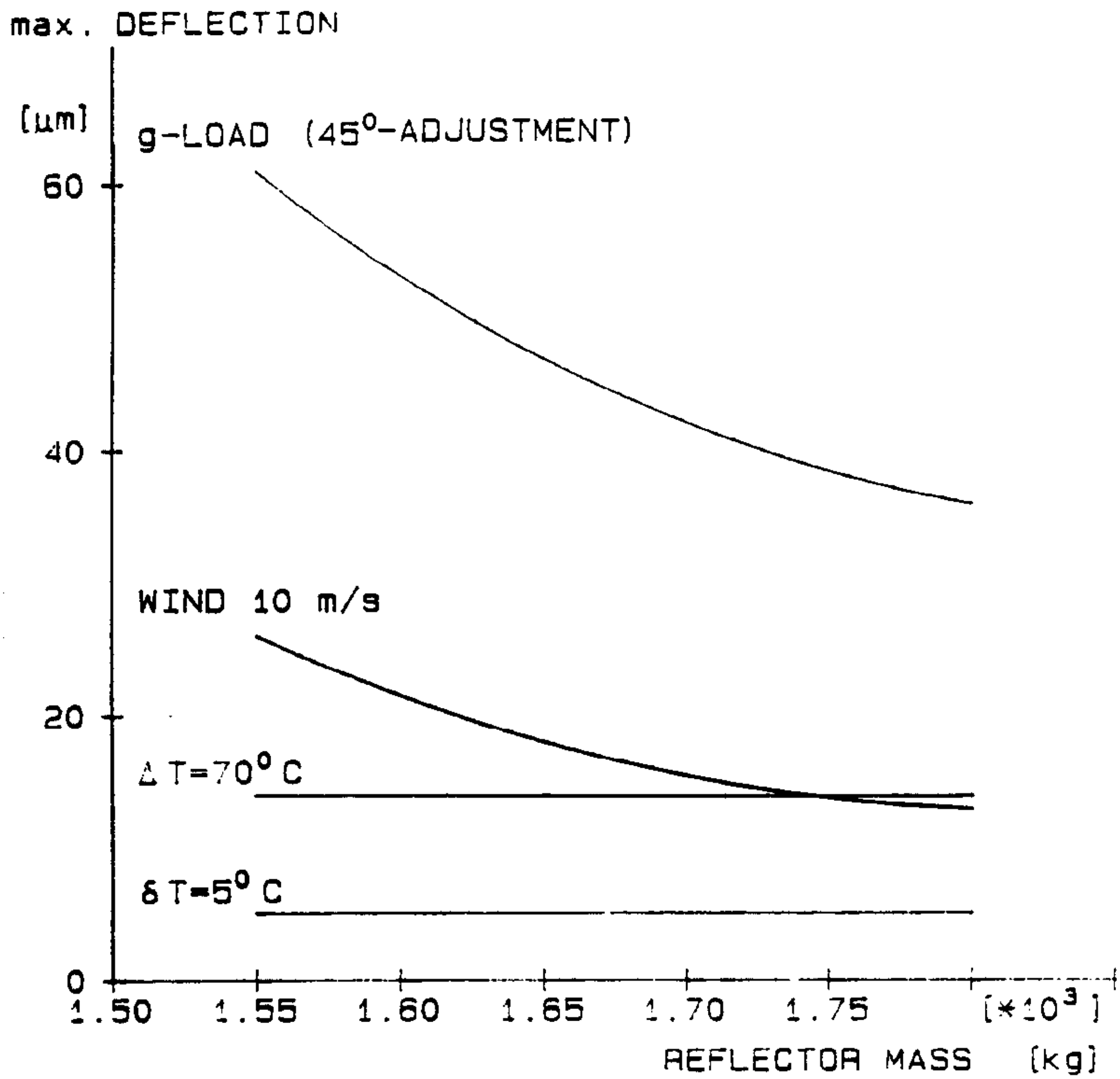

Fig. 2.14 MAXIMUM DEFLECTIONS VERSUS MASS
TUBULAR TRUSSWORK

2.2 Panel Concept

2.2.1 Basic Design

Two principle structure concepts for reflector panel design are possible.

- Monolithic Shell Design

- Sandwich Design

Fig. 2.15 and 2.16 present cross-sections of different panel concepts.

Fig. 2.15 shows a typical design concept for a [-blade stiffened monolithic skin concept. This is an usually low cost aluminium panel design for communication antenna application.

The [-blade stiffeners are riveted or bonded at the rear side of the preshaped panel surface.

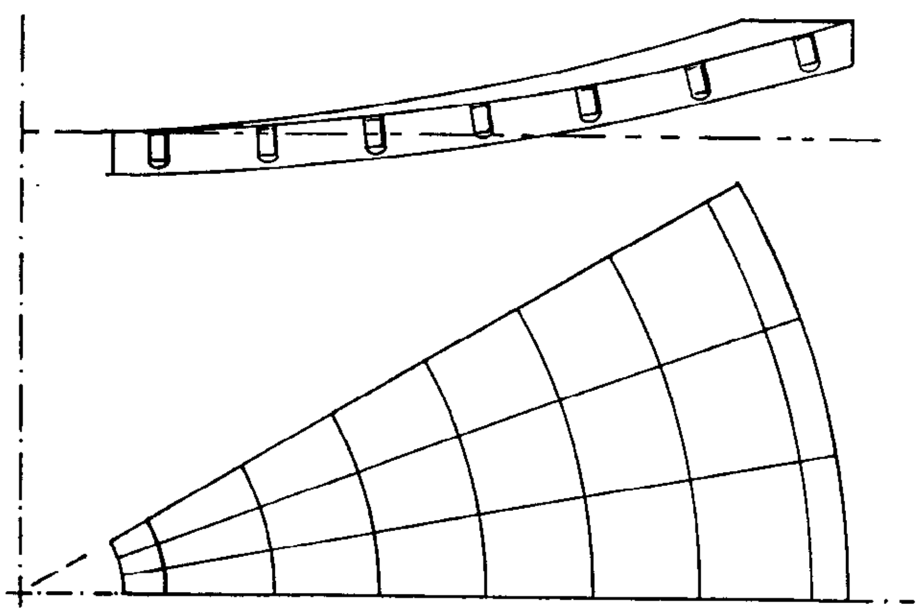

Fig. 2.15 [-Blade stiffened Aluminium Design

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Fig. 2.16 shows the design concept for a sandwich panel, which was used for the PRONAOS Balloon-Telescope project.

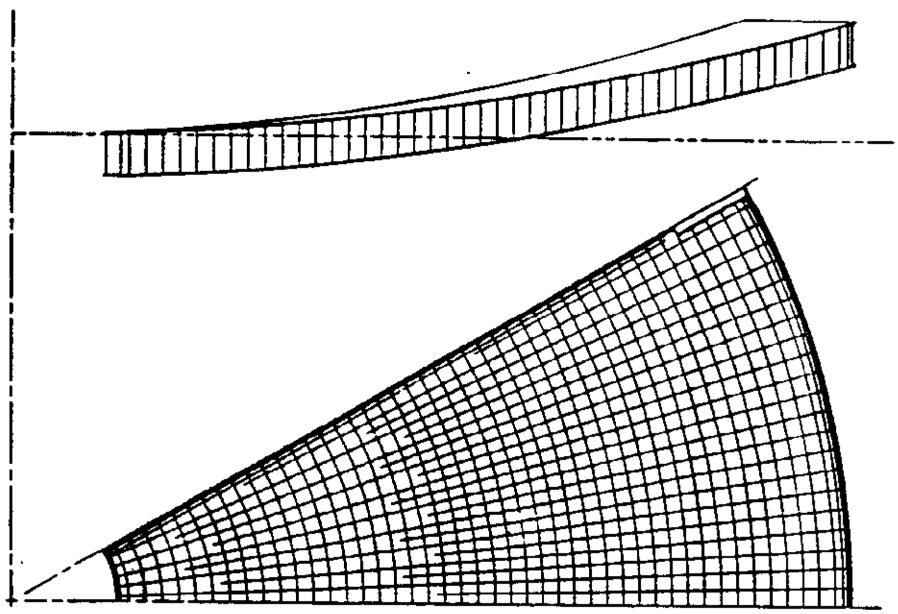
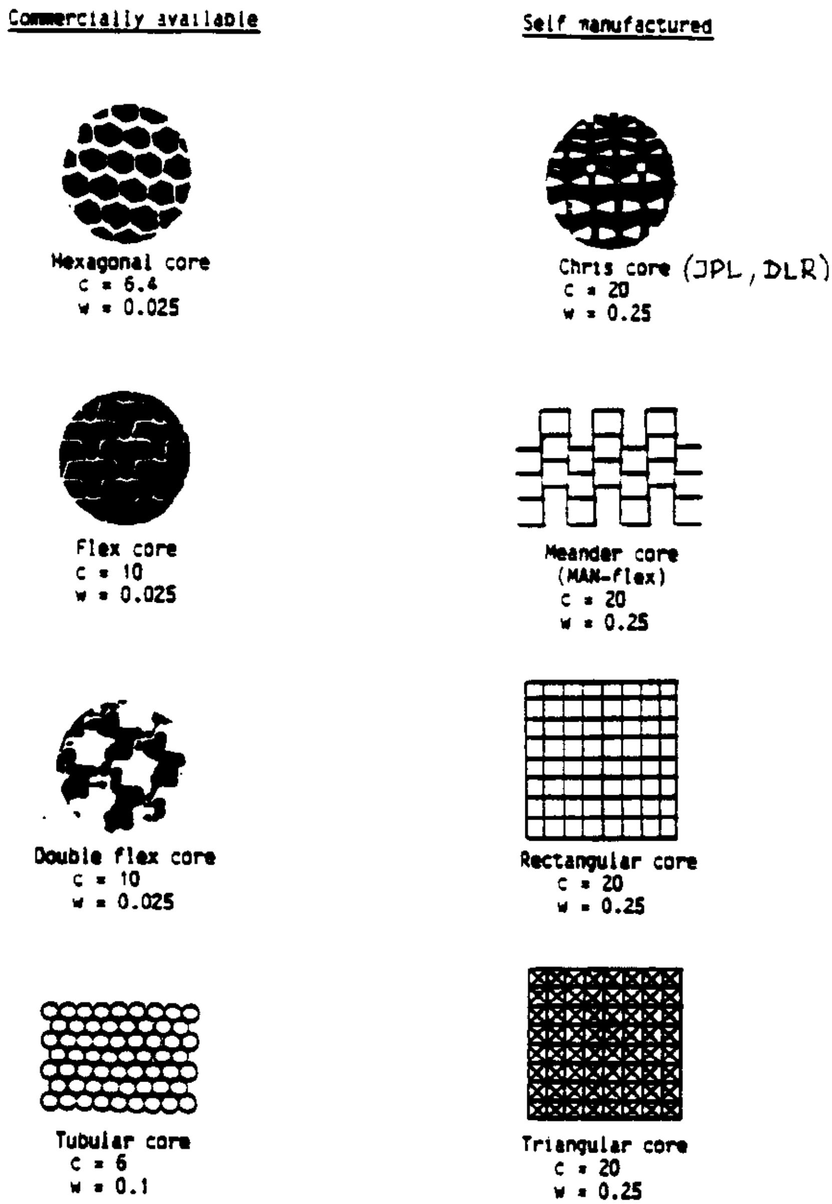


Fig. 2.16 Cross Section of the PRONAOS Reflector Panel

Different kinds of core material can be seen in Fig. 2.17. In the left column are listed commercially available core materials. The right column contains self manufactured core materials (as for PRONAOS).

Depending on performance requirements of the panel, the skin and core material can be selected either metal or FRP.

For the self manufactured core material more freedom in the choice of the suitable material is given.



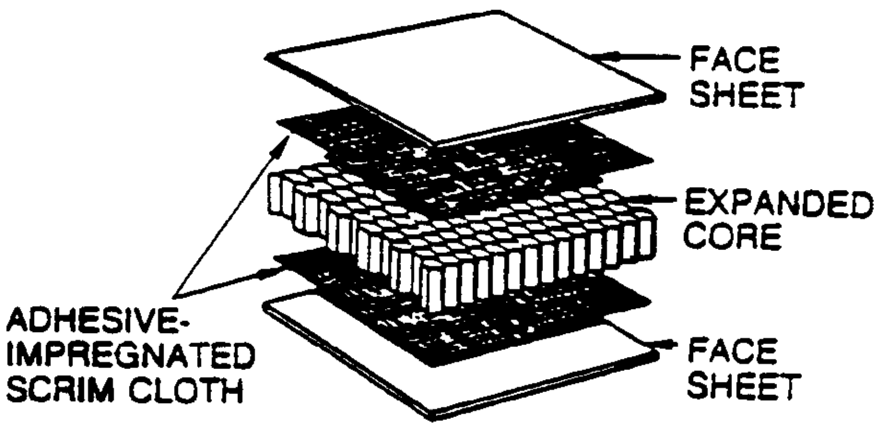
Cross Sections of Different Cell Types
for a Sandwich Honeycomb Structure

c = nomial cell size (mm)
w = nominal cell - wall thickness (mm)

Fig. 2.17

Most of the self manufactured core material is not flexible. So the ribs have to be cutted in the right shape before core assembly.

The sandwich assembly, using a flexible core (e. g. Hexagonal), is shown in Fig. 2.18. Hereby the face sheets can be seperately premanufactured on the mold (two shot process), or the sandwich can be layed up in a one shot process.

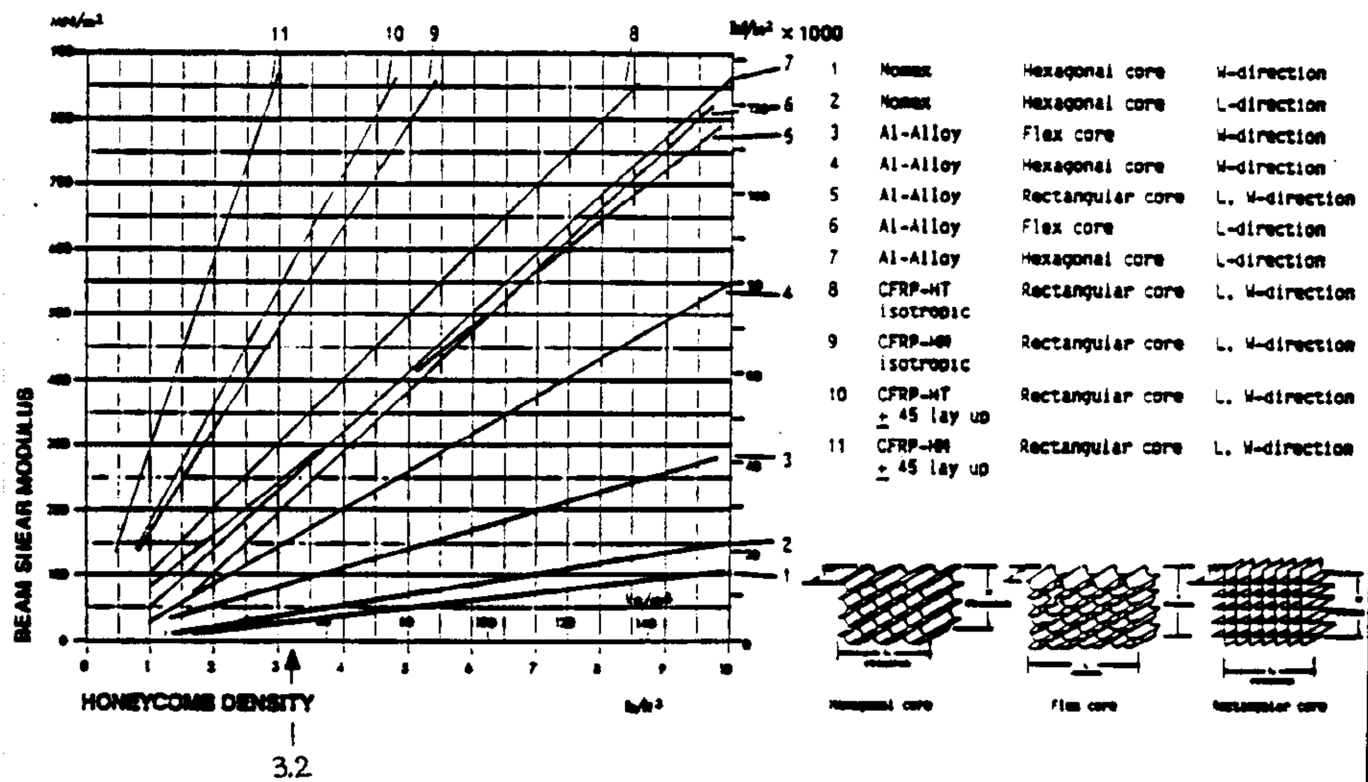


Sandwich Assemby for IRAM, SMT-Panels

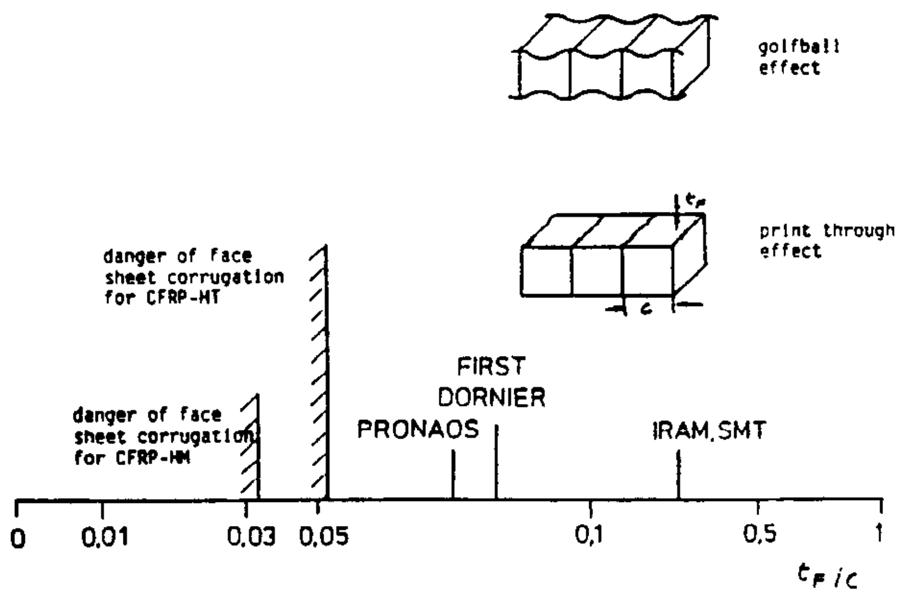
Fig. 2.18

Fig. 2.19 presents the beam shear modulus for different types of sandwich honeycomb.

Beam shear modulus of honeycomb



In Fig. 2.20 is demonstrated the danger of sandwich face skin corrugation depending on the ratio of the face skin thickness (t_F) to cell size (c).



Danger of Surface Corrugation in Sandwich Manufacturing Process

Fig. 2.20

The following Figures 2.21 to 2.23 present diagrams concerning the mechanical behaviour of panels based on tests and calculation results from the IRAM and SMT project. They show the possibilities of design with different characters of honeycomb.

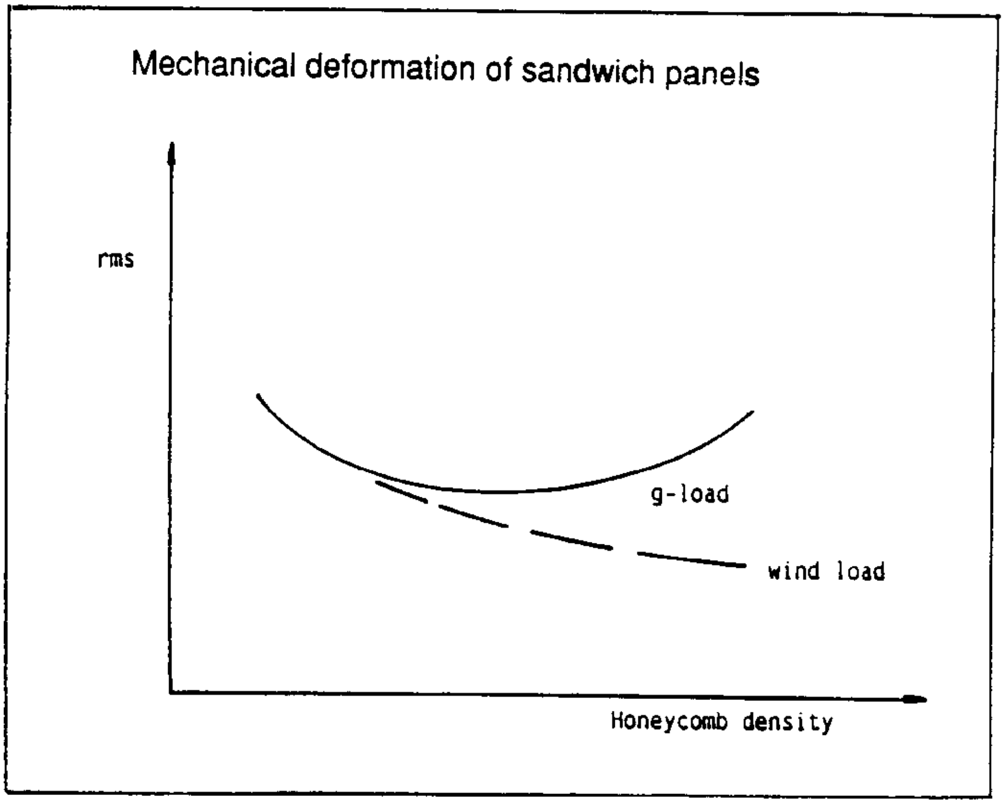


Fig. 2.21

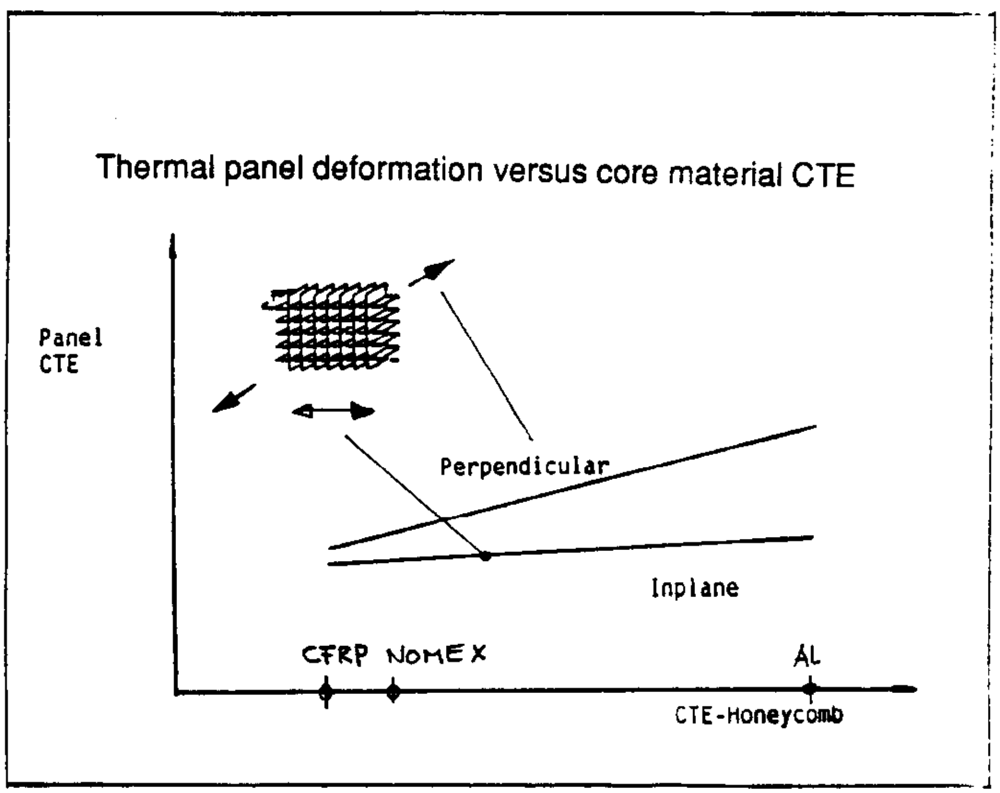


Fig. 2.22

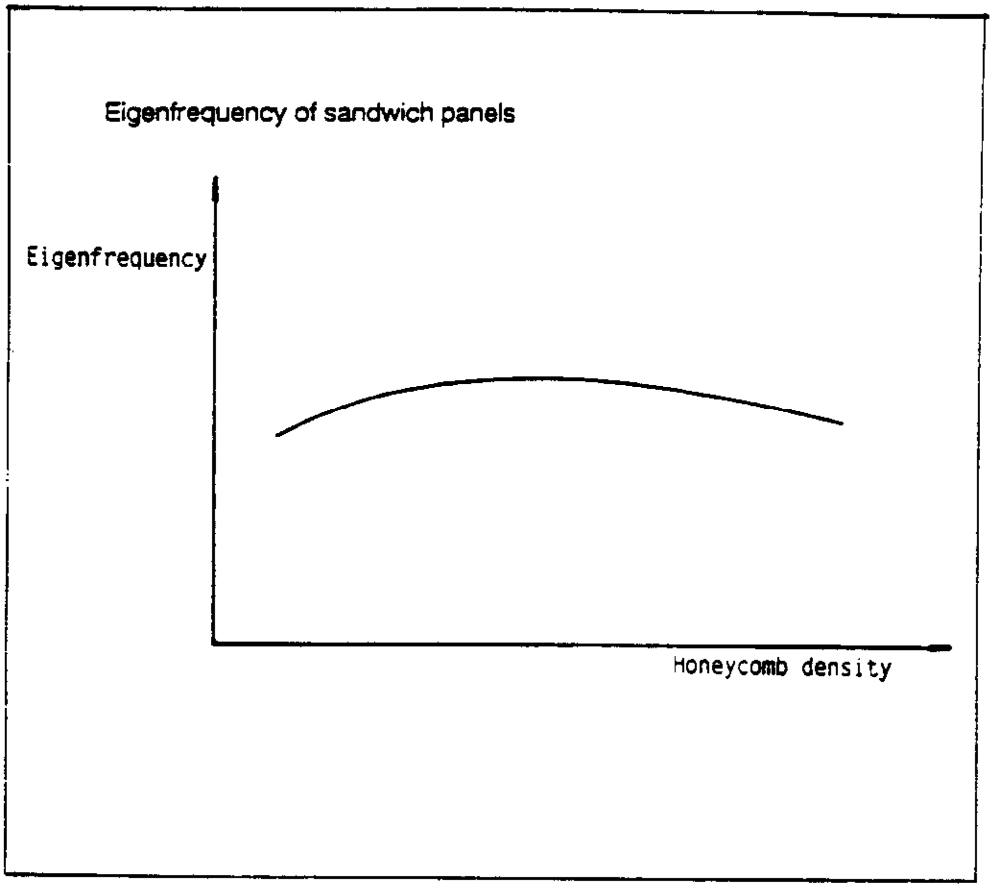


Fig. 2.23

These figures show the possibilities of optimum design with core. Latest calculations show an optimum at a density of 56 kg/m², which corresponds to a 3.2 core type in Fig. 2.19.

The strong influence of the alu CTE has to be compensated by fixations design.

The rms-value after manufacturing can be seen in Figures 2.24 to 2.26 for four telescopes. Each telescope has six ring. The inner-most ring has 16 panels and the other 5 rings are segmented in 32 panels. Figs. 2.2 and 2.24 show diagrams of the panel rms values of four telescopes due to panel area and radial tapering, (ration between inner side A and outer side B)

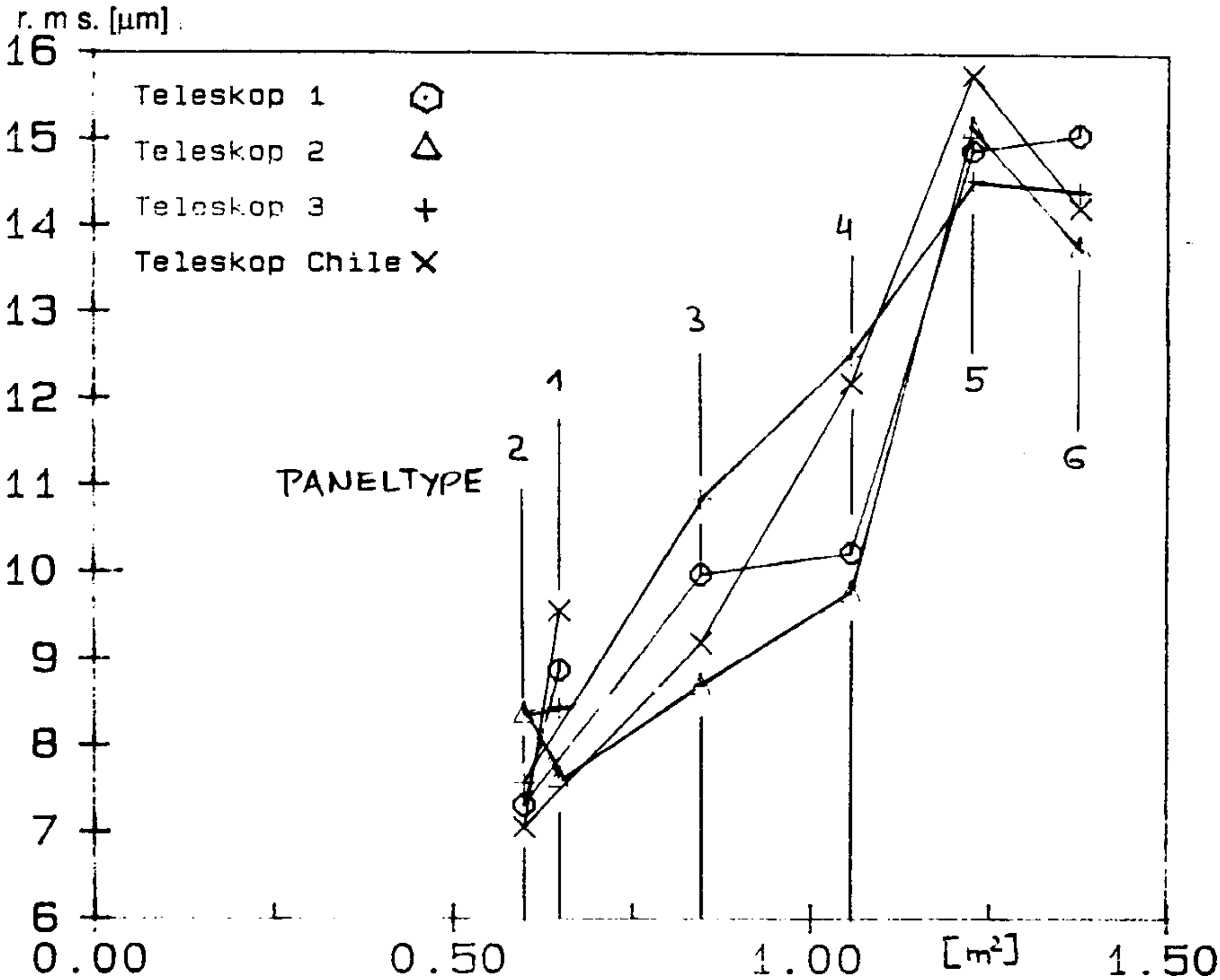


Fig. 2.24 Panel accuracy versus area

All diagrams show, that the required accuracy for SAO can be manufactured with a high number of repeatability.

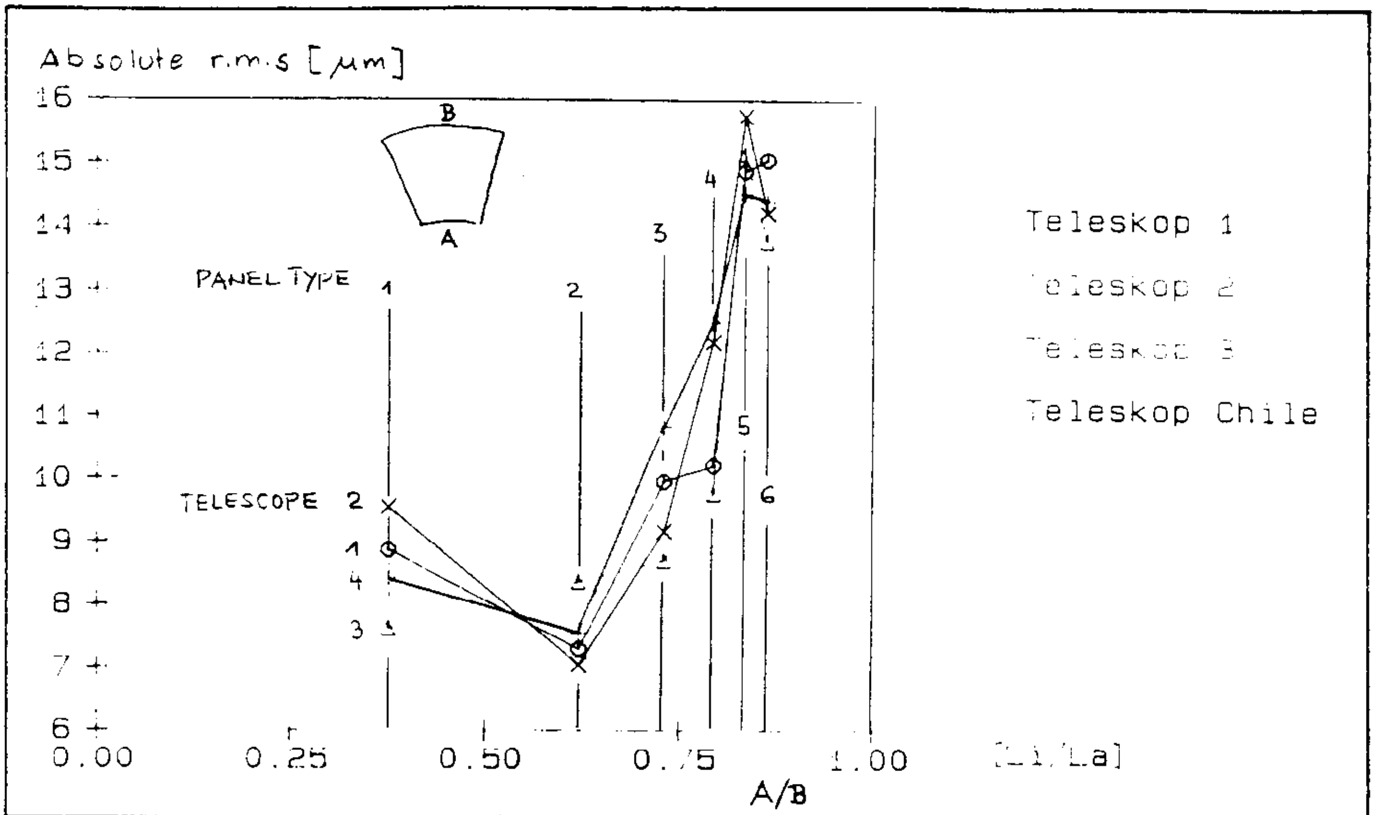


Fig.2.25 Panel accuracy
versus tapering

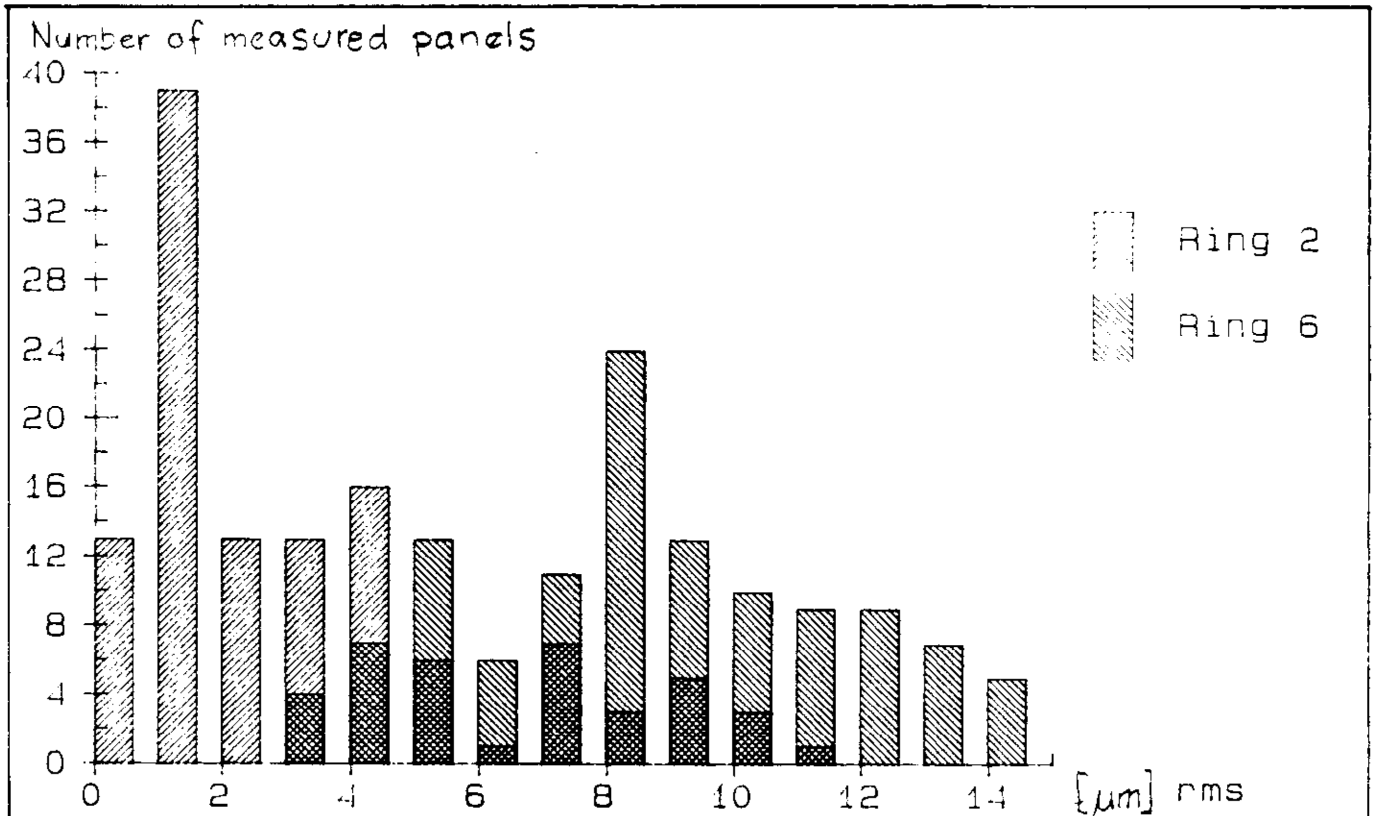


Fig. 2.26 Panel accuracy
(total number)

PANEL GEOMETRY

During optimisation process the 6 m telescopes became favourites. With the basic dimensions

6,0 m outer diameter
0,6 m inner diameter

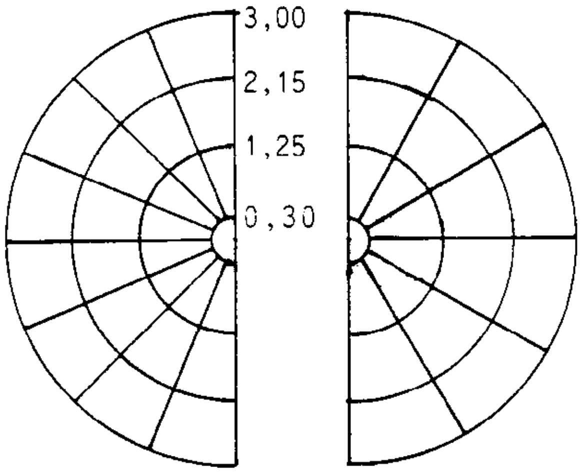
following panel geometries may be used.

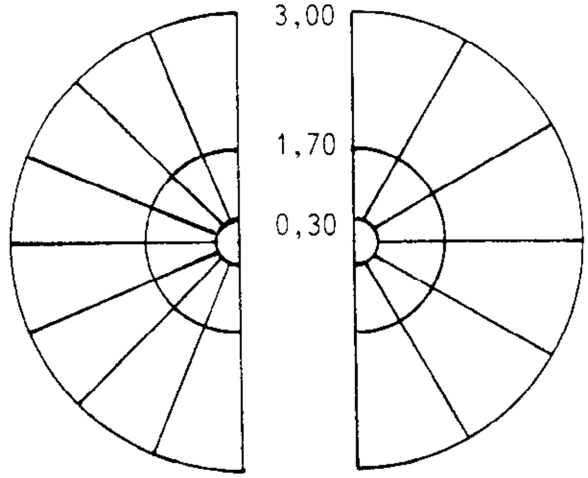
- 2 rings or 3 rings
- 12 segments or 16 segments per ring.

The absolute sizes given here will be found in the table below.

Rings / Panels	2			3		
mm	ti	ta	R	ti	ta	R
12	157	889	1,4	157	654	0,95
				654	1125	0,90
	889	1570	1,3	1125	1570	0,85
16	117	667	1,4	117	490	0,95
				490	843	0,90
	667	1177	1,3	843	1177	0,85

PANEL SIZE





	3 Rings [m]		2 Rings [m]	
segments	16	12	16	12
number of panels	48	36	32	24
max. length [mm]	950		1400	
max. width [mm]	1177	1570	1177	1570
max. area [m²]	0,85	1,2	1,2	1,45

As result of all data we give the following

RECOMMENDATION:

- 2 rings

- 12 segments

- aluminium hexagonal honeycombe core

- Cfrp skins

- panel area 1 = 0,8 m^2
  2 = 1,45 m^2

- honeycombe density 3.2 (55 kg/m^2)

- honeycombe thickness app. 3 inch (75 mm)

2.3 Panel Adjustment

2.3.1 Adjustments

Experiences are available for

-simple mechanical adjustment (Pinguin)
- fine mechanical adjustment (SMT)
- electromechanical adjustment (IRAM)

Sketches are given on the next pages.

The comparison of the following tabel gives clear preferences for the electromecha nical system with the major advantages

- remote control
- accuracy
- adjustment capabilities.

With the MAN-GHH special measuring and adjustment computer program it was possible to settle the 848 points of one IRAM telescope within 1 day for the first alignment and within 4 hours for the following two steps to an accuracy of app. 60 µm rms with an actuator accuracy of 2 µm. This promises an alignment time for a 6 m SAO-reflector of 3 hours for the first alignment and 30 minutes for the following procedures.

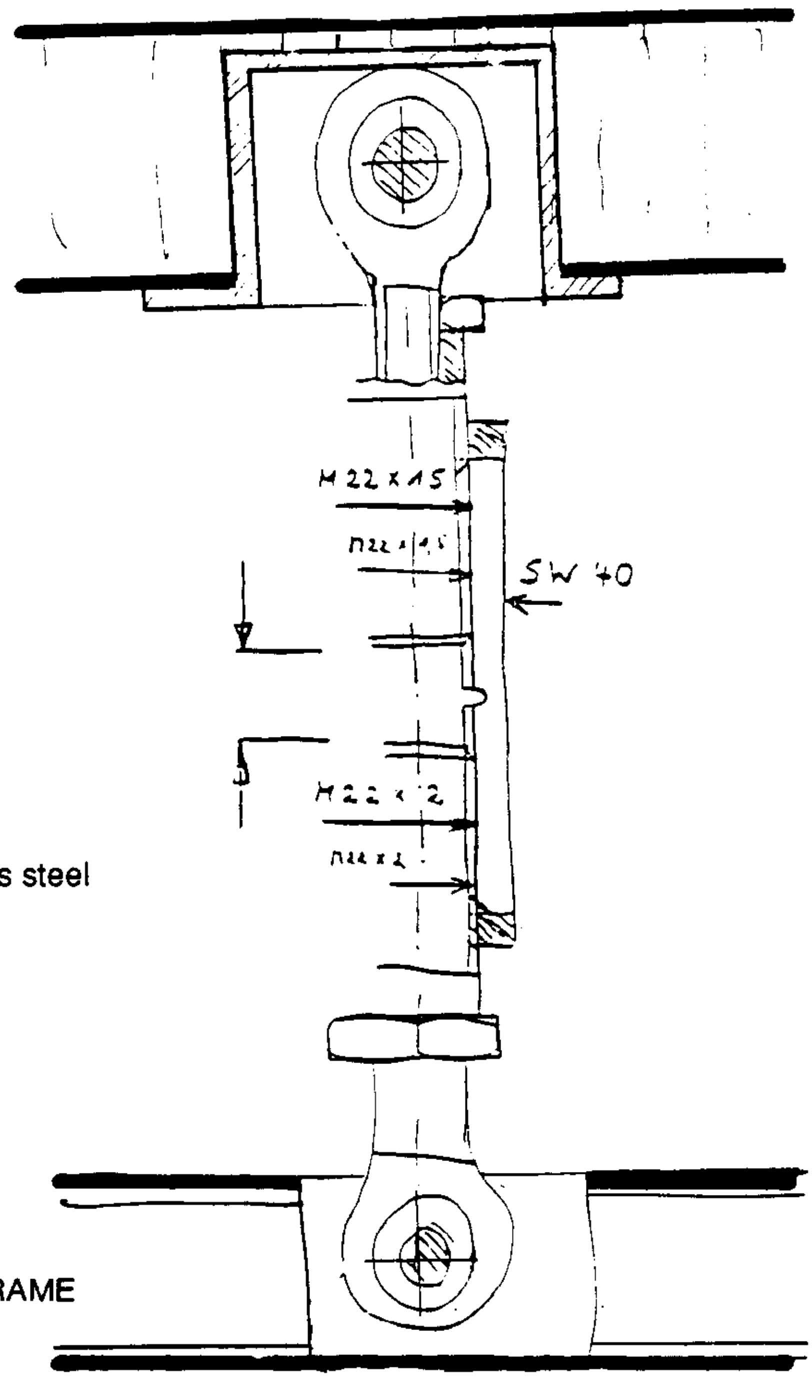
Under all circumstances the fixation point of the panels must be close to the surface. The strut must be rectangular to the surface.

PANEL ADJUSTMENTS

	SIMPLE	FINE MECHANICAL	ELECTRO
Accuracy µm	5	3	2
Total way mm	30	10	25
Fine way mm	15	2	25
Speed mm/min	0,2	0,2	1,6
Mass per unit g	280	200	500
Repeatability µm	5	3	2
Remote control	no	no	yes
Access to reflector	yes	yes	no
Price per unit (DM)	100	300	490
Supplem. installa-tions	no	no	wires
Adjustment dur. op.	no	no	yes

rlmusm1

PANEL ADJUSTMENT SIMPLE MECHNICAL



Accuracy	5µm
Total way	30 mm
Fine way	15 mm
Mass per unit	280 g
Material:	stainless steel Invar

Concept Pinguin by MAN-GHH

Fig. 2.27

PANEL ADJUSTMENT FINE MECHANICAL

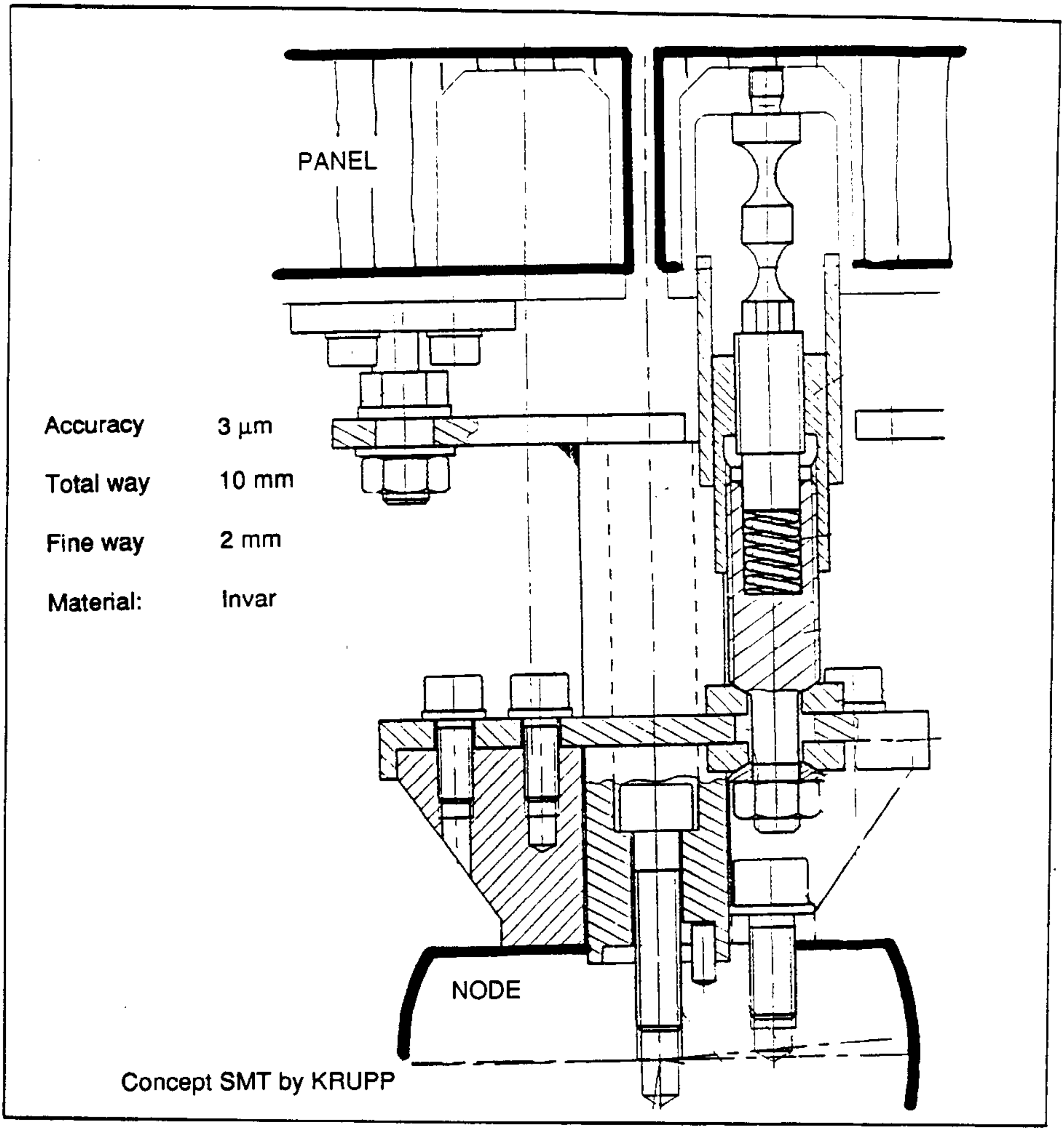
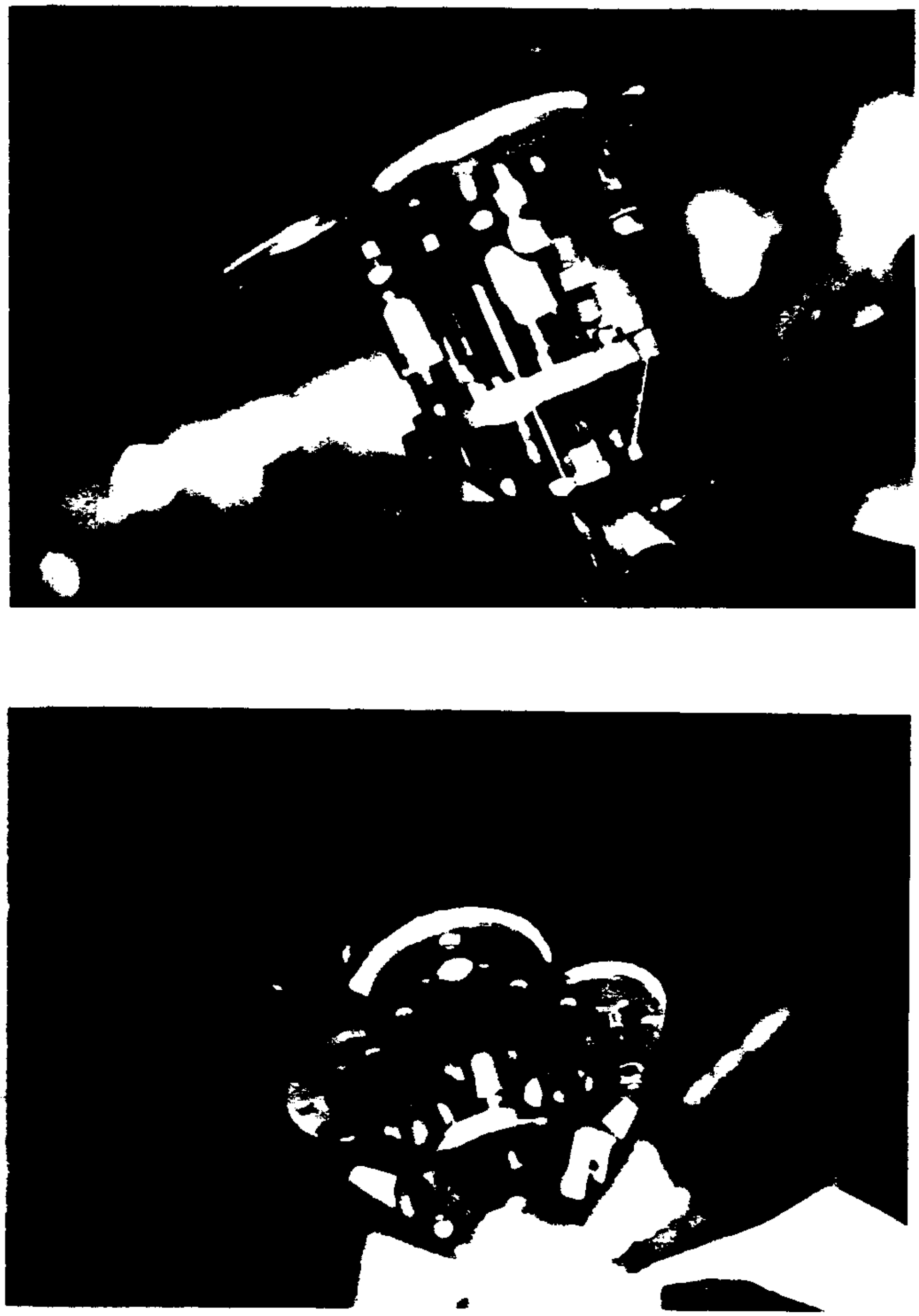


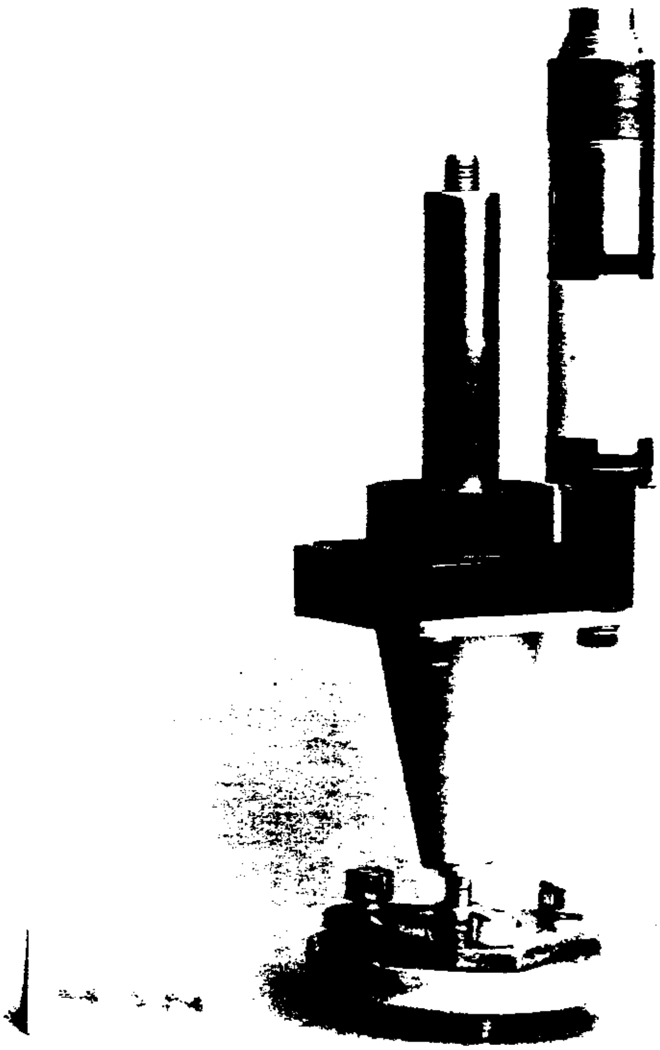
Fig. 2.28 Fine mechanical adjustment



PANEL
ADJUSTMENT

SMT-TYPE
BY KRUPP

Fig. 2.29 Fine adjustment of SMT under installation



Single actuator with 12 V-DC-motor

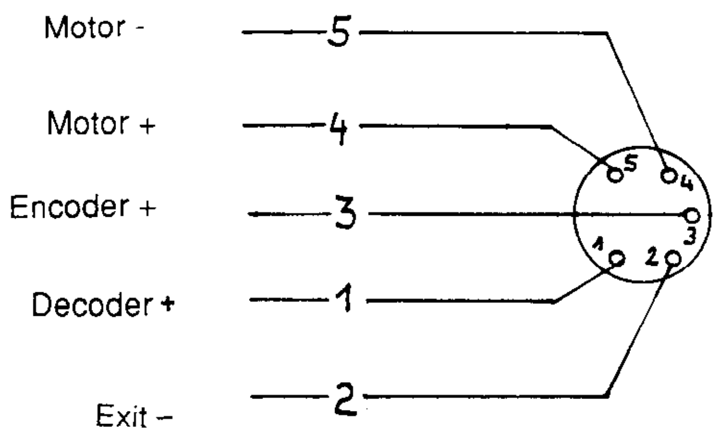
- Accuracy:
  2 µm
- Max. way:
  25 mm
- Max. speed:
  1,6 mm/min
- Weight:
  500 g
- Size:
  50 x 50 x 200 mm
- Operation temperature:
  -25°C to 20°C

Fig. 2.30

To connect the actuators to the grid a standard wiring system will be used.

Following plug scheme is standard, to operate the actuator and to count the bits given bach by the encoder:

Side of actuator:

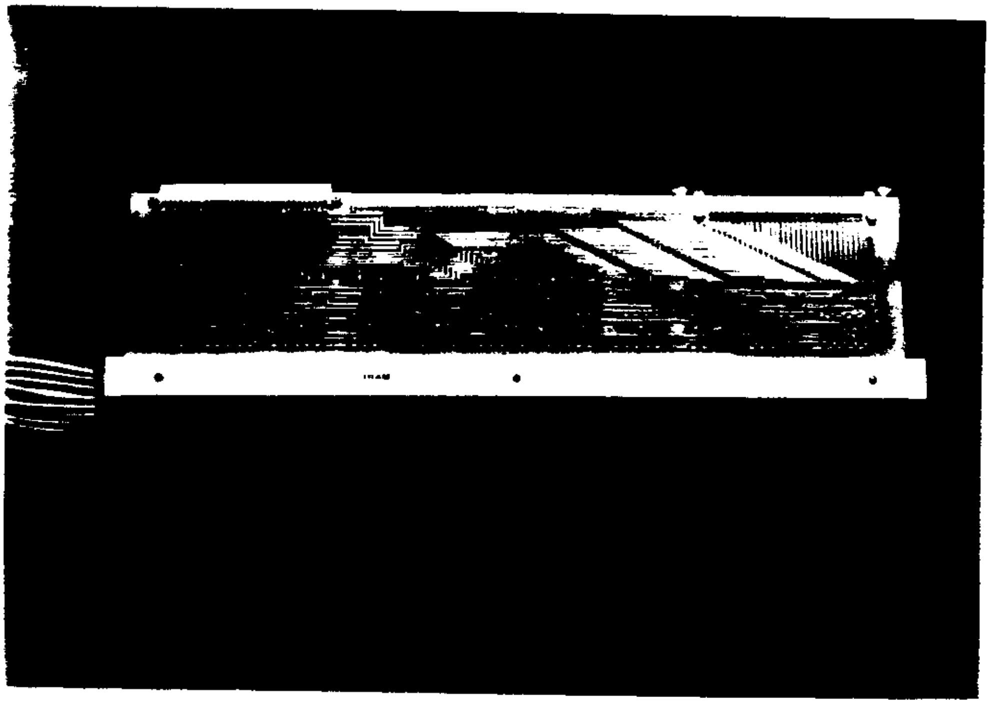


All other plug systems fitting with the actuator external diameter can be used on request. The plugs will be sealed after connection to prevent corrosion. As cable will be used the standard type (or a requested one) with a mass of 150 g/m:

Following the back up structure to the central hub or the cabin any type on connection can be used. As the IRAM system is already tested we propose to use this system.

All actuators may then be actuated by a central computer system.

rimusm1



5868-18-1

Fig. 2.31 Actuator Connection (IRAM design)

All actuators will be delivered with a final checkout protocol with oscillogram of voltage during final test.

BCHM — Stellantrieb Subreflektor

Prüfung mit einer Druckkraft von 1000 N axial auf die Schubstange

Verfahrweg	40 mm ↓ 40 mm ↑ 10 mm ↓
Stromaufnahme des Motors bei ↑	260 mA
Stromaufnahme des Motors bei ↓	116 mA
Oszillogramm	Bild Nr. 1
Kontrolle	[signature]

BCHM — Stellantrieb Subreflektor

Prüfung mit einer Druckkraft von 1000 N axial auf die Schubstange

Verfahrweg	40 mm ↑ 40 mm ↓ 10 mm ↑
Stromaufnahme des Motors bei ↑	240 mA
Stromaufnahme des Motors bei ↓	85 mA
Oszillogramm	Bild Nr. 1
Kontrolle	[signature]

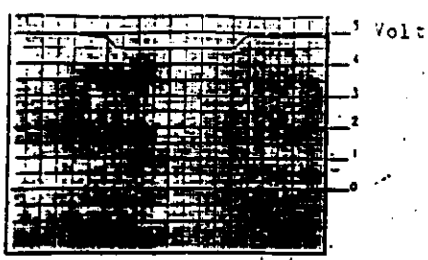


Bild 1 — 1 ms

Bild 2 — 1 ms

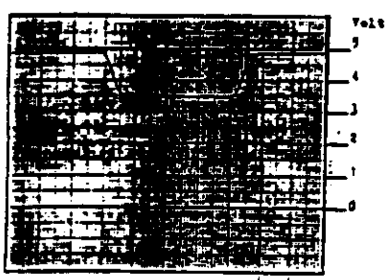


Bild 3 — 1 ms

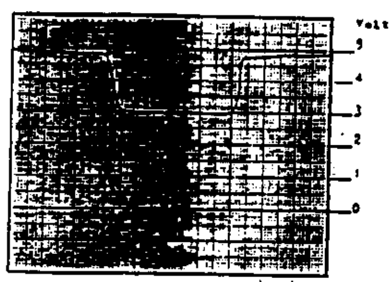


Bild 4 — 1 ms

Fig. 2.32 Test protocol of actuators

RADIOTELESCOPE PANELS

Single actuator with 12 V-DC-motor

- Accuracy: 2 um
- Max. way: 25 mm
- Max. speed: 1,6 mm/min.

Assembly of 15 m-radio-telescope panels with electrical actuators.

Each panel is fixed with 5 actuators.

RL/6205-5-11/PFEB2

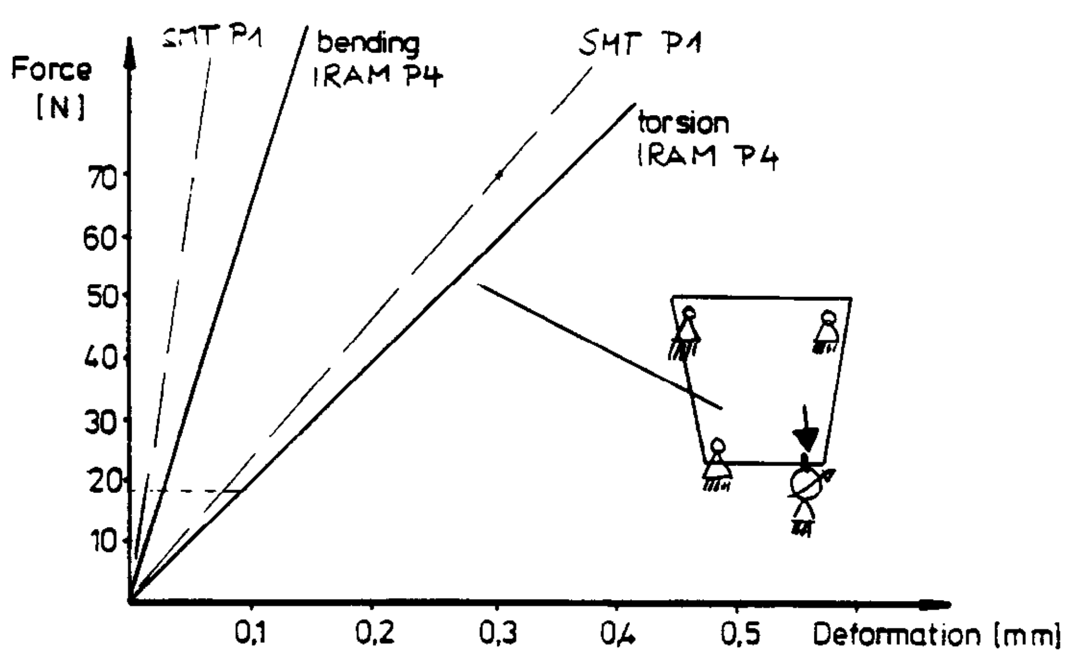
2.3.2 Number of fixations

Focussing on minimum mass and cost the fixation of all panels with an isostatic mount of three points will be the optimum. The maunfacturing process and the required high accuracy of the panels leads to a solution with one point more.

The reasons for four points per panel are following

- rejection of app. 20 per cent panels due to low accuracy,
- result in much higher cost than that one for the actuators and cables,
- possibility to adjust panels after longer time of exposure to the right surface shape.

These reasons are the results of MAN experience with the four 15 m telescopes and former metal telescopes. The basic stiffness of the panels is designed to be the bending stiffness against gravity and wind load. With a sandwich thickness between 58 mm (IRAM) and 90 mm (SMT) measurements are available for the torsional stiffness and the possibility to deform the panels to the right contour (Fig. 2.34).



Panel stiffness under bending and torsion

Fig. 2.34

rimusm1

Following the two figures one can see that as example the IRAM Panel type 4 No. 134 was measured with a rms value of 33 μm.

This value out of specification may be caused by the addition of several small mistakes:

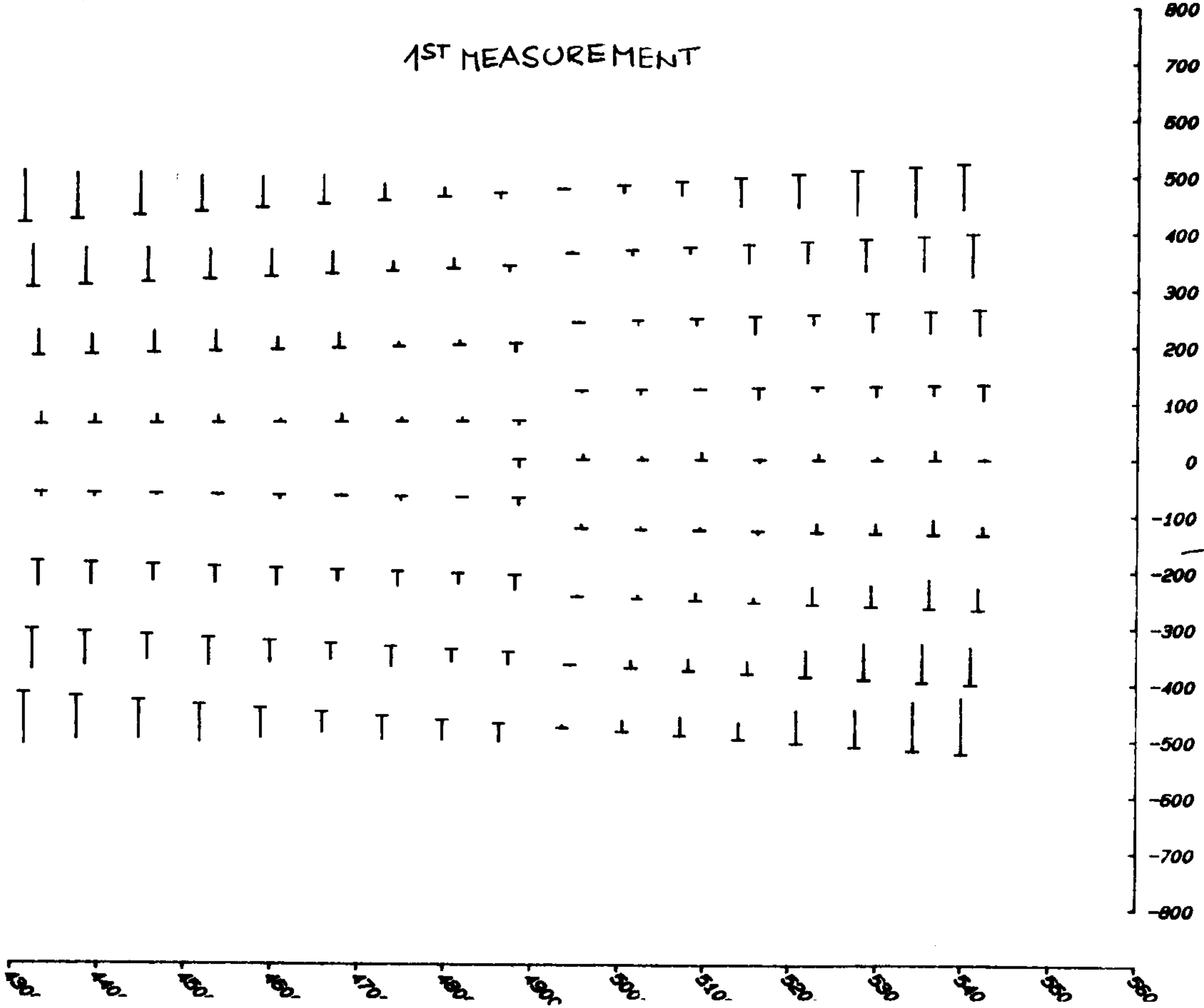
- inaccurate fibre orientation
- spread in resin content
- spread in honeycomb stiffness
- unsymmetric curing process caused by autoclave or oven
- failure during coating
- differences in foil thickness and stretching

The principal behaviour of the panel is still obtained and guaranteed with respect to the static and thermal behaviour.

Adjusting the panel in one corner (in this case with deformation of 120 μm at one fixation point the panel can be corrected to the value of 7 μm rms which is better than the specified value of 20 mm). The force which is necessary therefore will be 18 N, a value given by measurements shown in the Figure 2.34.

After assembly of 4 telescopes at the moment and an operation experience of more than 3 years with telescope 1 of Plateau de Bure no negative results can be found. After extensive discussions with Dr. van Hoerner this system and technique will also be used for the SMT and should be used for SAO as a practical and optimum way.

T2



IRAM

Panel 4

Datum 20. JULI 87.

Serialnr P4134

rms= .033 mm

max. Abweichung
(laengs Normale)
= .085 mm

= .085 mm

feste Parameter:

	Mitte	Normale
x	4887.297	-.448
y	0.000	0.000
z	1224.906	.894

optim. Parameter

YZ-Rotation:
-.043

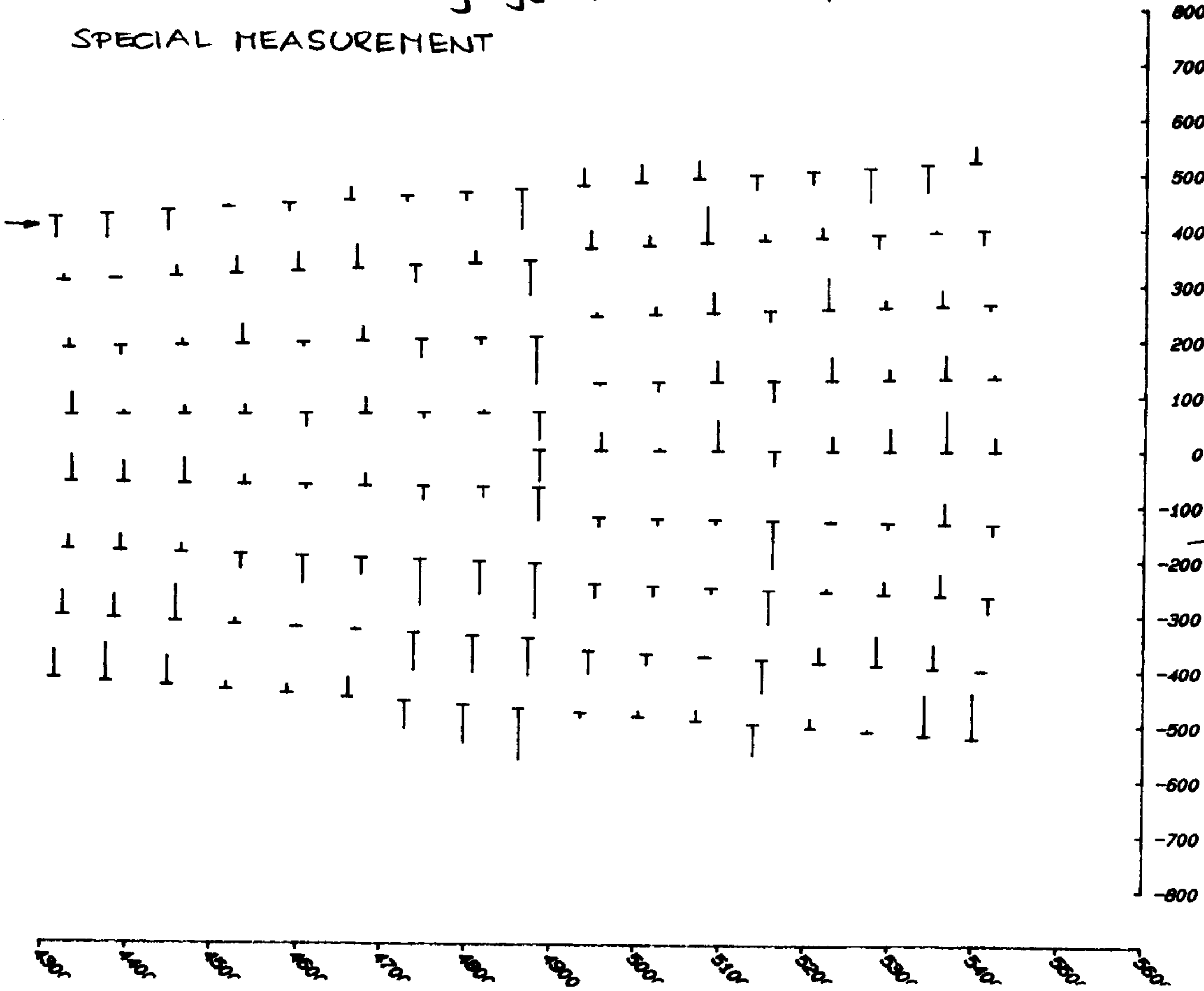
XZ-Rotation:
-.009

Normaltranslatio
.011

TELESKOP 2

Sondervermessung gem. E-PN-477

SPECIAL MEASUREMENT



IRAM

Panel 4

Datum 20. JULI 87.

Serialnr P41342

rms= .007 mm √

max. Abweichung
(laengs Normale)
= -.018 mm

| = .018 mm

feste Parameter:

	Mitte	Normale
x	4887.297	-.4481
y	0.000	0.0000
z	1224.906	.8940

optim. Parameter

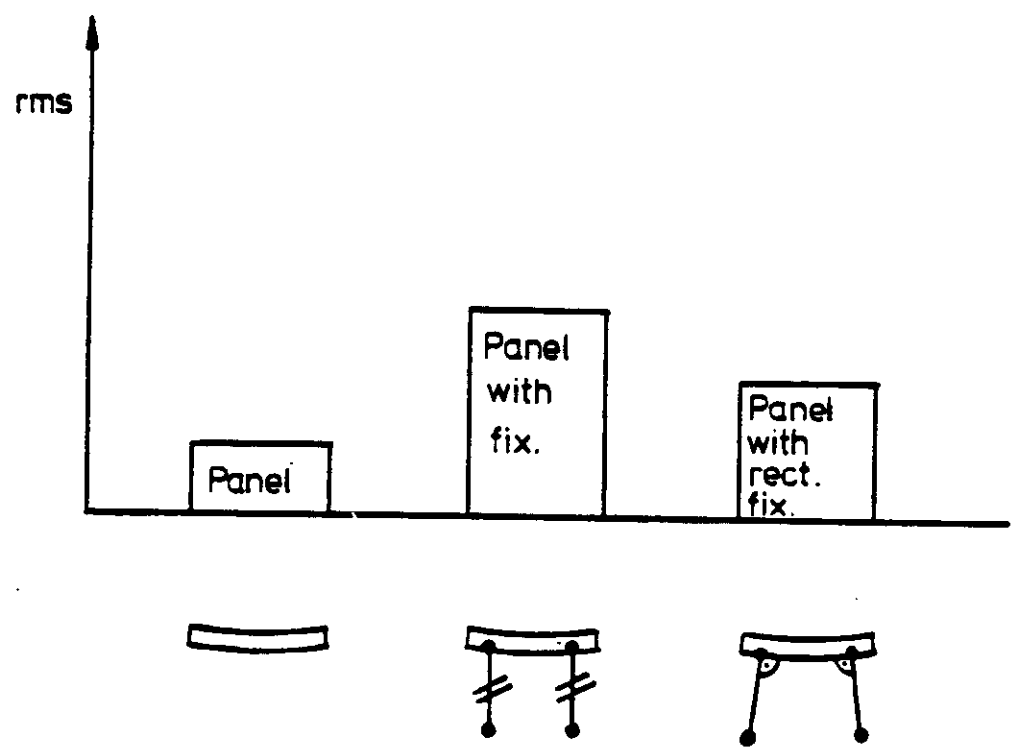
YZ-Rotation:
-.033

XZ-Rotation:
-.009

Normaltranslation
.010

2.3.3 Orientation of fixations

Detailed analysis for the SMT-panels have shown that only fixations rectangular to the front skin will fit the specification values. The difference of bare panel, with fixations rectangular to panel corner area and rectangular to surface is shown in the following figure. Besides the different stiffnesses of fixations not rectangular to the panel also geometric reasons cause a non homogenious deformation of the reflector surface.



Difference of rms-values for panels without and with fixations (example SMT)

Fig. 2.36

rlmusm1

2.3.4 Location of fixation point

The optimum points for fixation would be about 20 % of panel length towards the middle. Large lever arms or a complex panel structure is the result. Lever arms are under bending and heavy. A good compromise is a location close to the node of strut connection to reduce bending moments. This gives an approximate distance of 60 to 100 mm from all panel sides.

But also the lateral position is relevant and should be as close as possible to the front surface (see Fig. 2.28).

This avoids large temperature deformations of the core between this point and the surface. A "pot"-design is the result. But no direct connection to the front skin should be made by riveting or bonding. Both systems disturb the smoothness of the front skin and can be seen during temperature changes.

<u>RECOMMENDATIONS:</u>

Summing up all given assumptions and results one should use the following system:

- four points per panel

- electromechanic actuators

- invar rods between actuator and panel

- "pot"-design for fixation points

2.4 Thermal Systems

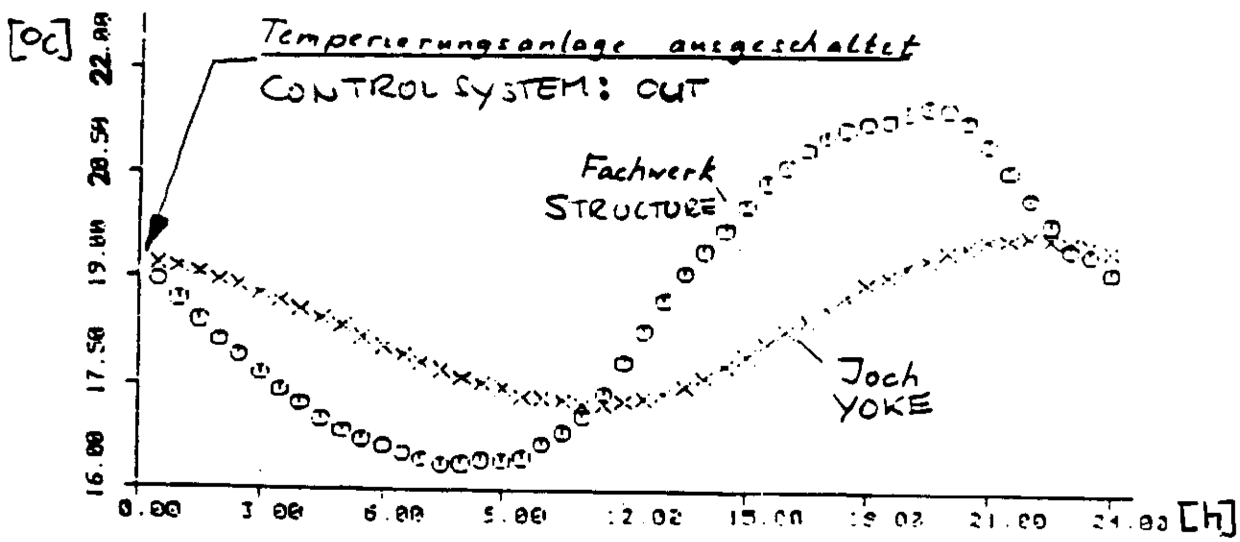
At the moment there is no clear specification on the site environment and on the whole telescope system with a rear cladding or an open structure.

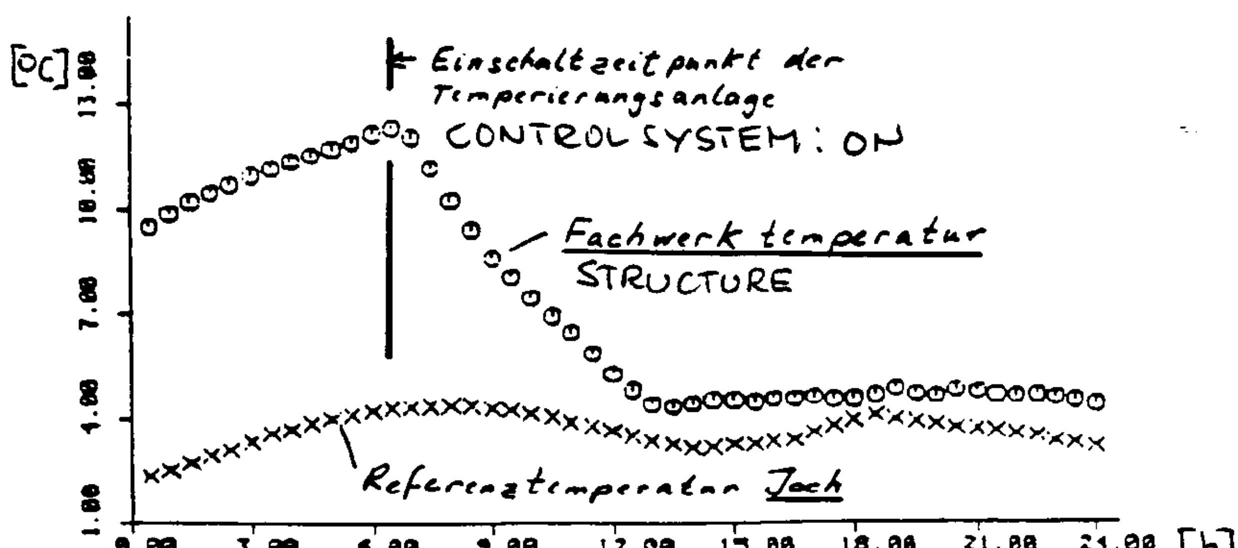
If any type of climatisation or deicing is necessary three different types are available.

2.4.1 Ventilation System

This system requires an insulating rear cladding and a temperature and ventilating system. Most experienced in this field is MAN-GHH, Dr. Kaercher, who designed the system for the IRAM 32 m Pico Veleta telescope. The system there achieves a temperature accuracy of 2 °C over the whole structure and allows the operation in the mm-wavelength region.

With continous heating the deicing is also possible.



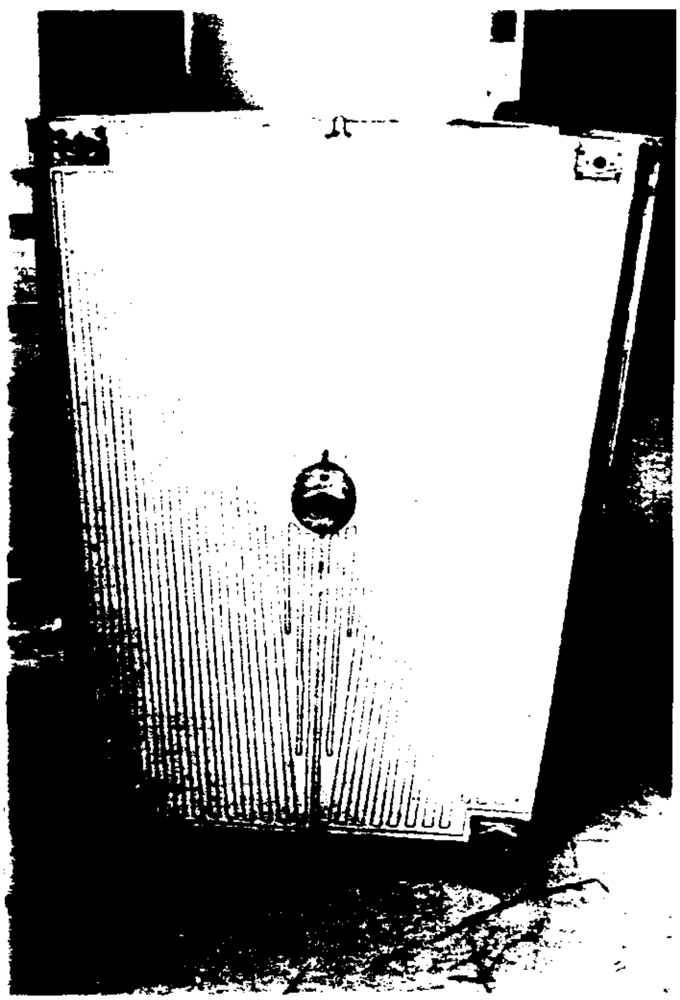


2.4.2 Standard electric heating

The termal conductivity of Cfrp reduces the efficiency of an infrared heating system with radiators in the rear side. Also an insulating rear cladding is necessary.

To improve the electrical system an electrical heating foil should be applied on the panel rear side.

The advantage is the flatwise heating of the panels and the possibility to int rate the insulation with the heating foil as a sandwich design.

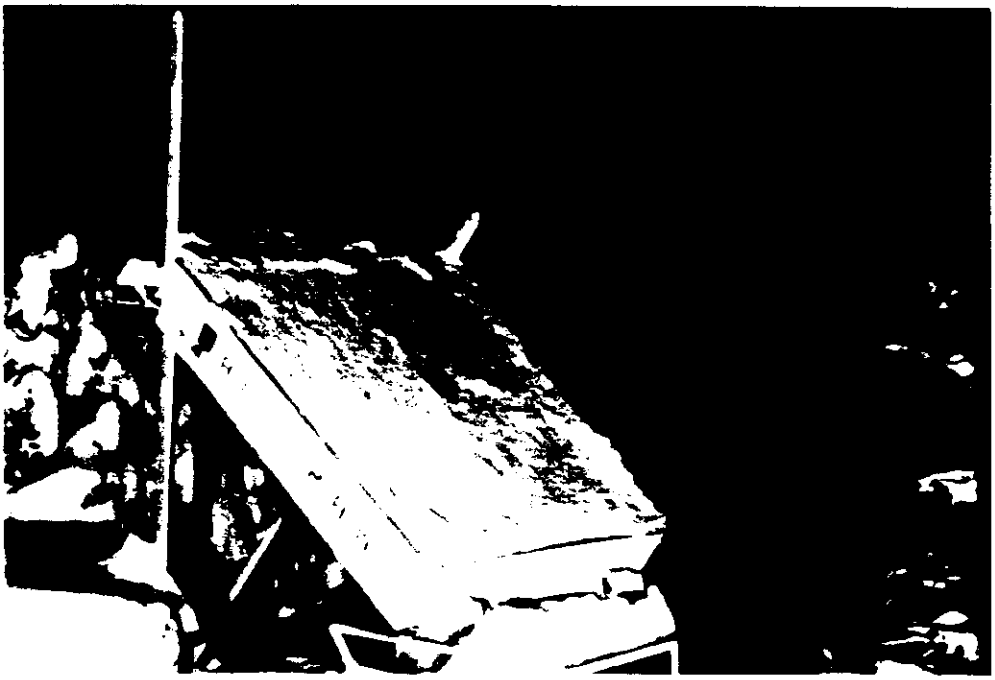


5392-10A

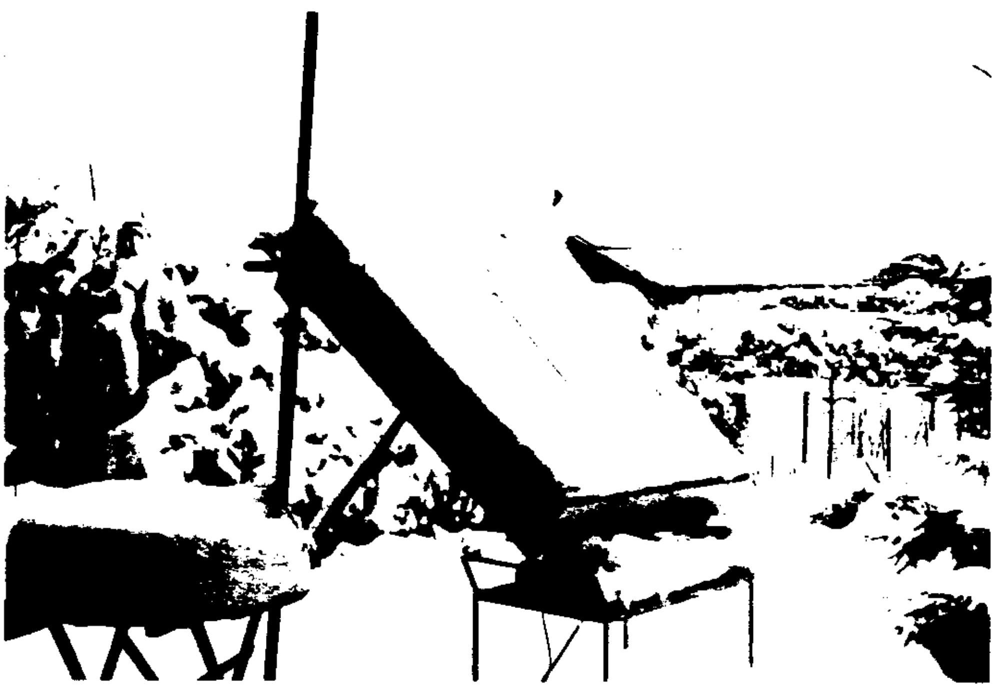
Fig. 2.28 Deicing foil (IRAM type)

After solving the manufacturing and soldering problems, which both led to corrosion problems in the beginning of IRAM these foils are operating well. Nearly the whole surface is deiced very rapidly as seen by tests.

These foils will be bonded over the whole rear side of the front panels and mechnically fixed for safety reasons.



5123-32



5123-34

Fig. 2.39 Deicing tests with bonded heating foil on panel rear side.

Looking onto the whole telescope a grid of panel size can be seen. This results from the panel structural design which does not allow to heat the whole side.

6420-1-3

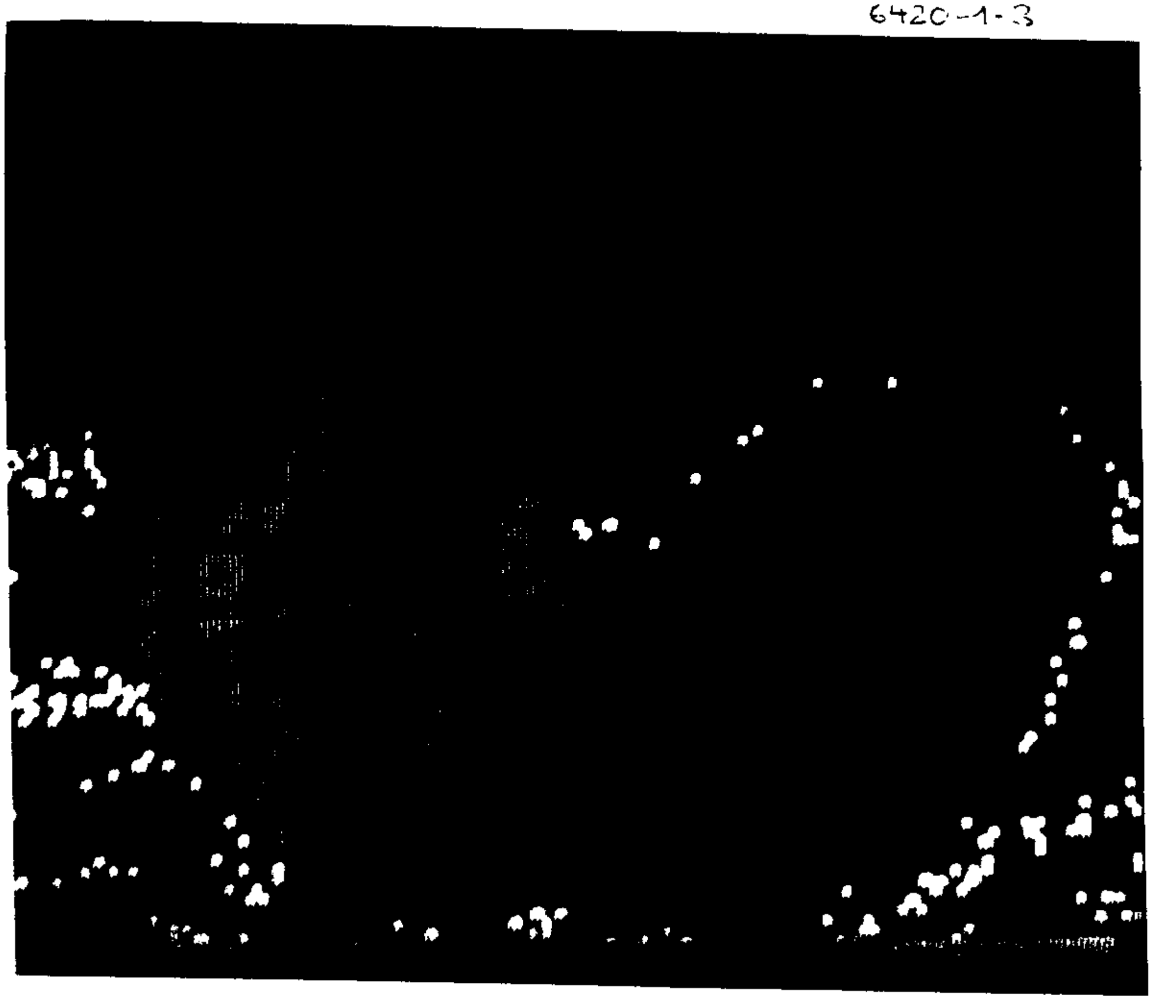


Fig. 2.40 Deicing of IRAM reflector

Infrared pictures taken during final acceptance on Plateau de Bure show the unique temperature distribution over all panels per segment and across the total reflector surface.

2.4.3 Integral heating system

A further inprovement is given by the patented integrated heating system (IHS). The heating wires or foils are integrated in the front skin of the panel. This results in a minimum energy consumption, minimum deicing time and reduced insulation on the panel rear side. No rear cladding is necessary as the panel itself acts as an insulator.

One disadvantage is the impossibility to repair the heating wire itself without exchanging the panel. A solution is than to use the foil system on he rear side of the panel. The second disadvantage is a 10 % higher CTE of the whole panel systems.

The just invented system was used a doubled wiring lay up, so that redundancy is given.

Experiments have been very successful and one panel is under operation of Plateau de Bure since October 1988. The same system will be used on the Antarktis Telescope but with aluminium panels.

RECOMMENDATION:

If deicing is necessary one should use the IHS.

2.5 Materials

The standard reflector materials are for millimeter antennas:

- aluminium
- Cfrp

A comparison of the characteristics is given in the following table and diagrams:

- Table 2.4.1 Material characteristics

- Fig. 2.42 Young's modulus
- Fig. 2.43 Specific young's modulus
- Fig. 2.44 Specific shear modulus

For panel design also the relative values

- specific stiffness (e. g. Youngs modulus devided by specific weight) and
- specific shear stiffness (e. g. shear modulus divided by specific weight)

are valid to realize a light weight and stable panel.

Strength is normally not a design contraint as the panels are designed for stiffness. Therefore the safety factors against ultimate strength - also under dynamic loads are in the range of 5.

Table 2.4.1

Material Characteristics

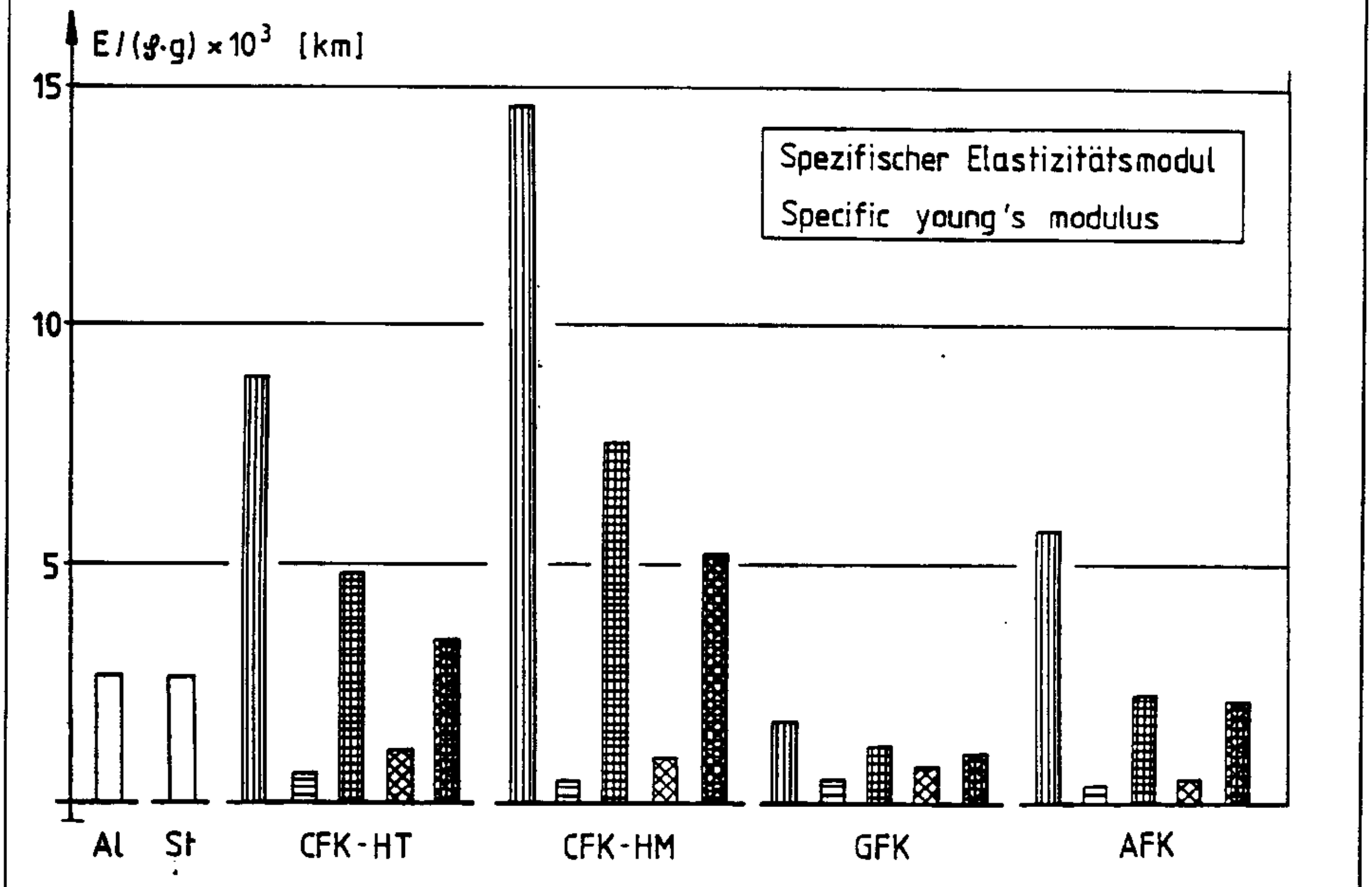
ZFB - interm. fibre fracture
FB - fibre fracture

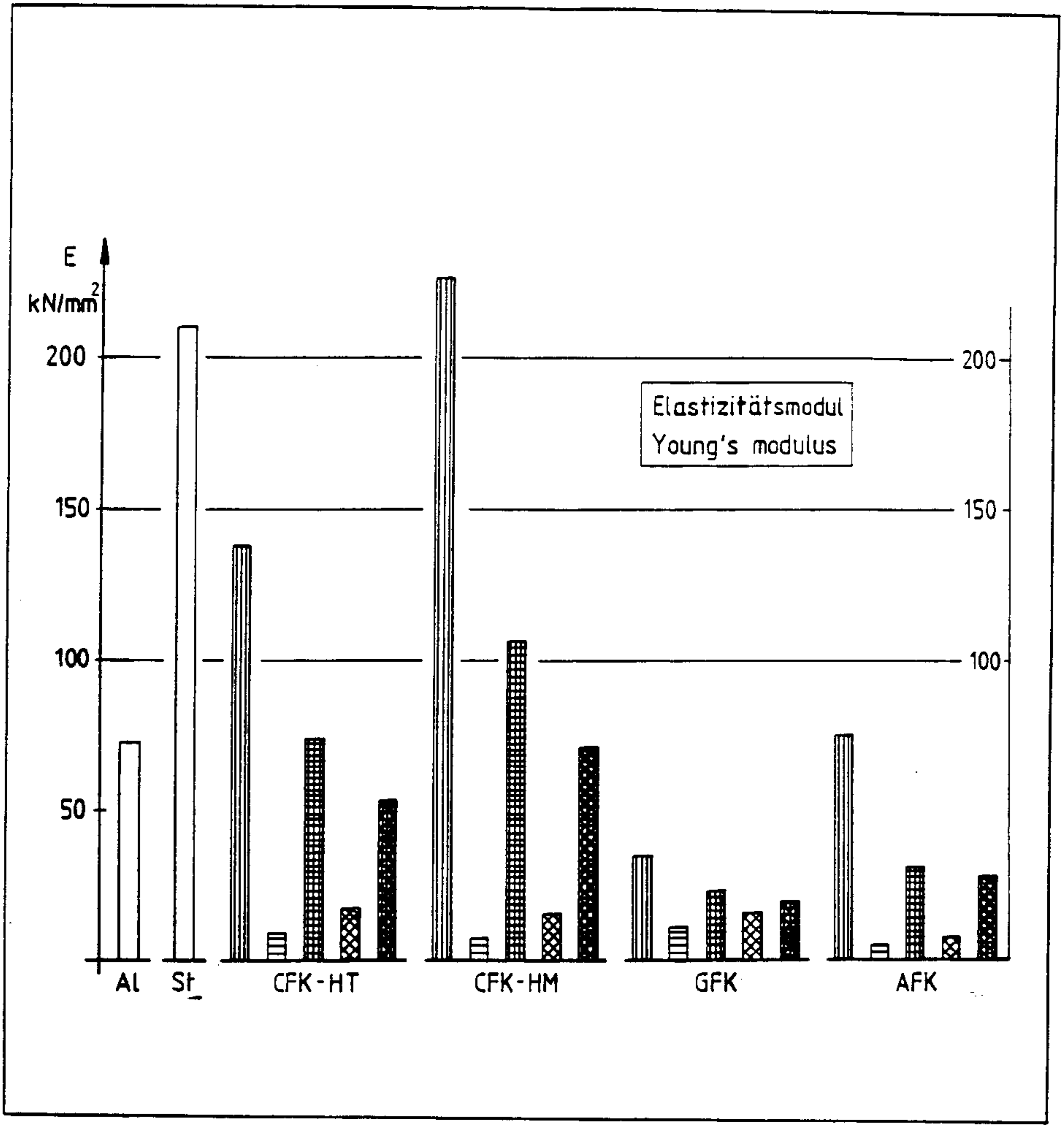
Material		σ_{zB} (N/mm²)	σ_{dB} (N/mm²)	E (kN/mm²)	τ_B (N/mm²)	G (kN/mm²)	Density g/dm³
GFRP	0°	$\sigma_{\|\|zB}$ = 730	$\sigma_{\|\|dB}$ = 700	$E_{\|\|}$ = 47	60	5.3	2,000
	±45°	$\sigma_{\perp,zB}$ = 95	$\sigma_{\perp,dB}$ = 110	$E_{\perp}$ = 16	(ZFB) 124 (FB) 430	13	
SFRP	0°	$\sigma_{\|\|zB}$ = 1,250	$\sigma_{\|\|dB}$ = 282	$E_{\|\|}$ = 78.5	45	1.7	1,400
	±45°	$\sigma_{\perp,zB}$ = 72	$\sigma_{\perp,dB}$ = 110	$E_{\perp}$ = 6.3	146	20	
HT-CFRP	0°	$\sigma_{\|\|zB}$ = 1,706	$\sigma_{\|\|dB}$ = 1,000	$E_{\|\|}$ = 135	93	5.3	1,520
	±45°	$\sigma_{\perp,zB}$ = 170	$\sigma_{\perp,dB}$ = 198	$E_{\perp}$ = 18.5	526	35	
HM-CFRP	0°	$\sigma_{\|\|zB}$ = 1,418	$\sigma_{\|\|zB}$ = 775	$E_{\|\|}$ = 224	76	5.0	1,600
	±45°	$\sigma_{\perp,zB}$ = 140	$\sigma_{\perp,z\partial}$ = 163	$E_{\perp}$ = 18.66	400	57.3	

frictional coefficients

CFRP
HM - other materials 0.15 - 0.30
HT - against soft materials (HV < 1000) 0.4 - 0.7
HT - against hard materials 0.13 - 0.2

MAN TECHNOLOGIE


E / (ϱ·g) × 10³ [km]
15
10
5
Spezifischer Elastizitätsmodul
Specific young's modulus
Al
St
CFK-HT
CFK-HM
GFK
AFK


E
kN/mm²
200
150
100
50
Elastizitätsmodul
Young's modulus
Al
St
CFK-HT
CFK-HM
GFK
AFK

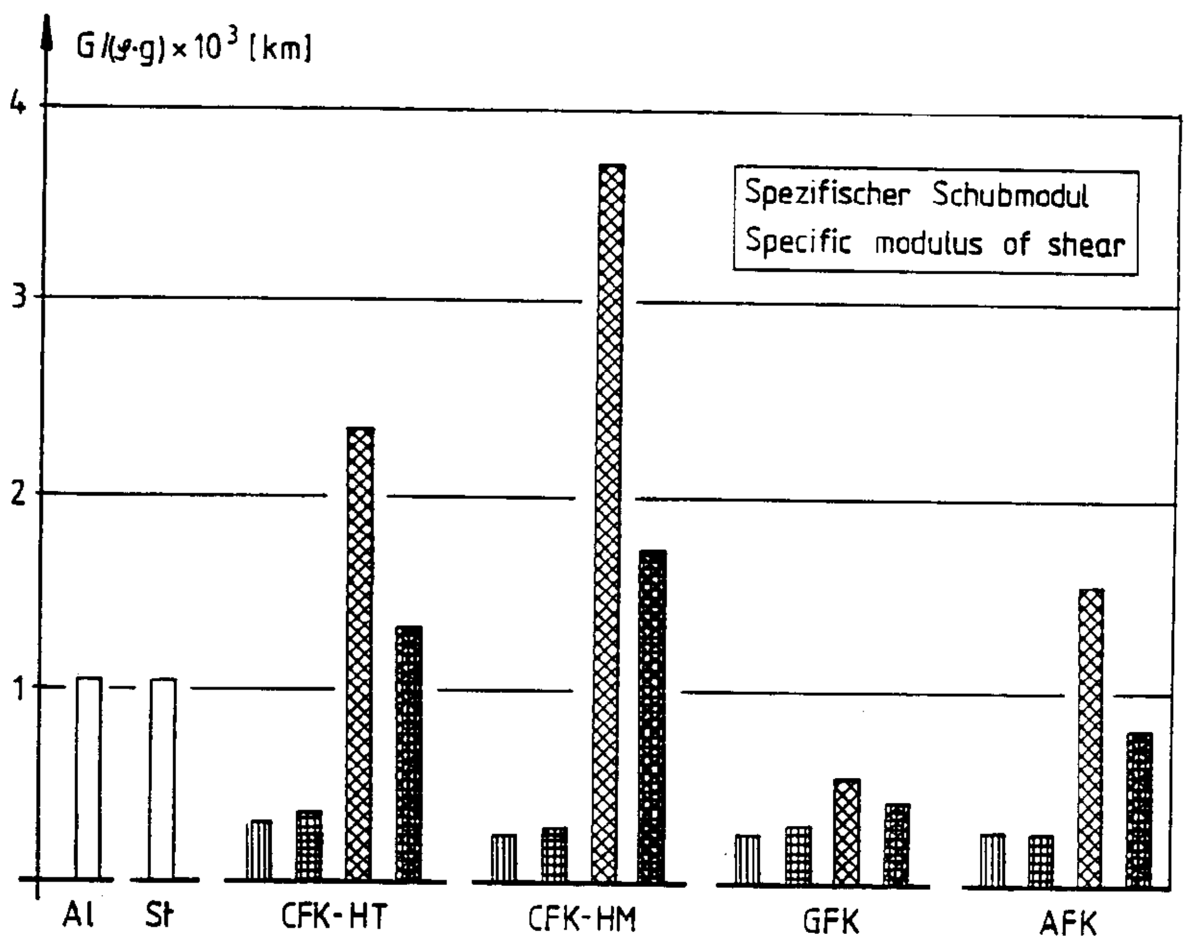

G /(ρ·g) × 10³ [km]
4
3
2
1
Spezifischer Schubmodul
Specific modulus of shear
Al
St
CFK-HT
CFK-HM
GFK
AFK

Fig. 2.44

MAN TECHNOLOGIE

THERMAL COEFFICIENTS

One of the most important coefficients for an efficient millimeter telescope is CTE-coefficient of thermal elongation. Only by very expensive climatisation of the telescope structure and panel surface operation in the mm-wavelength range is possible with metal material. Energy costs for the Pico eleta telescope are in the range of 300.000 DM per year, whereas all 3 Plateau de Bure telescopes need only 20.000 DM per year for telescopes this solution is necessary and the optimal and economic solution. In the required accuracy range no full Cfrp-panel with Cfrp skins and core is necessary.

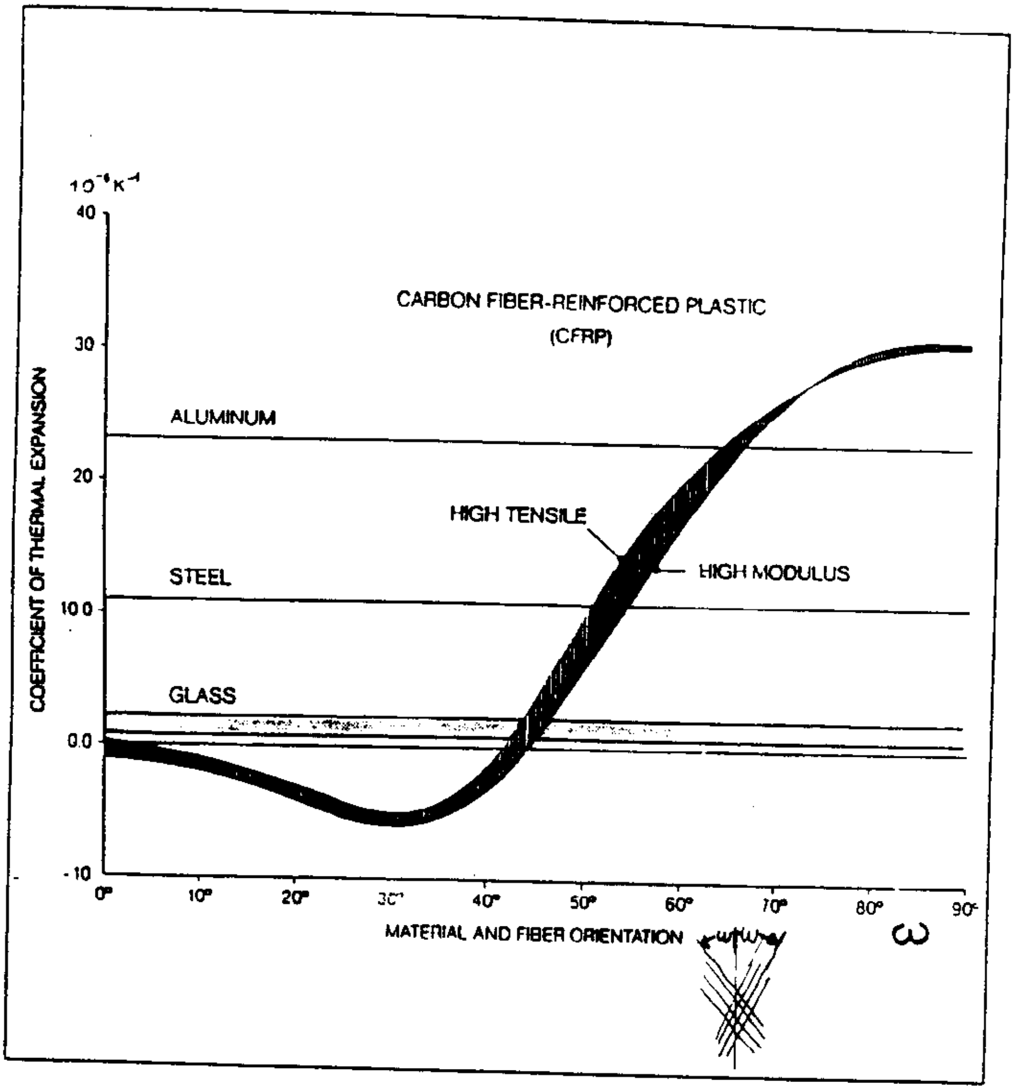


Fig. 2.45: CTE

The results given by holographic measurement and finite element calculation confirm this assumption.

The CTE for fibers is related to the fiber orientation. This means, that unidirectional lay ups can be made with a CTE of zero, but multidirectional layers have realistic values above.

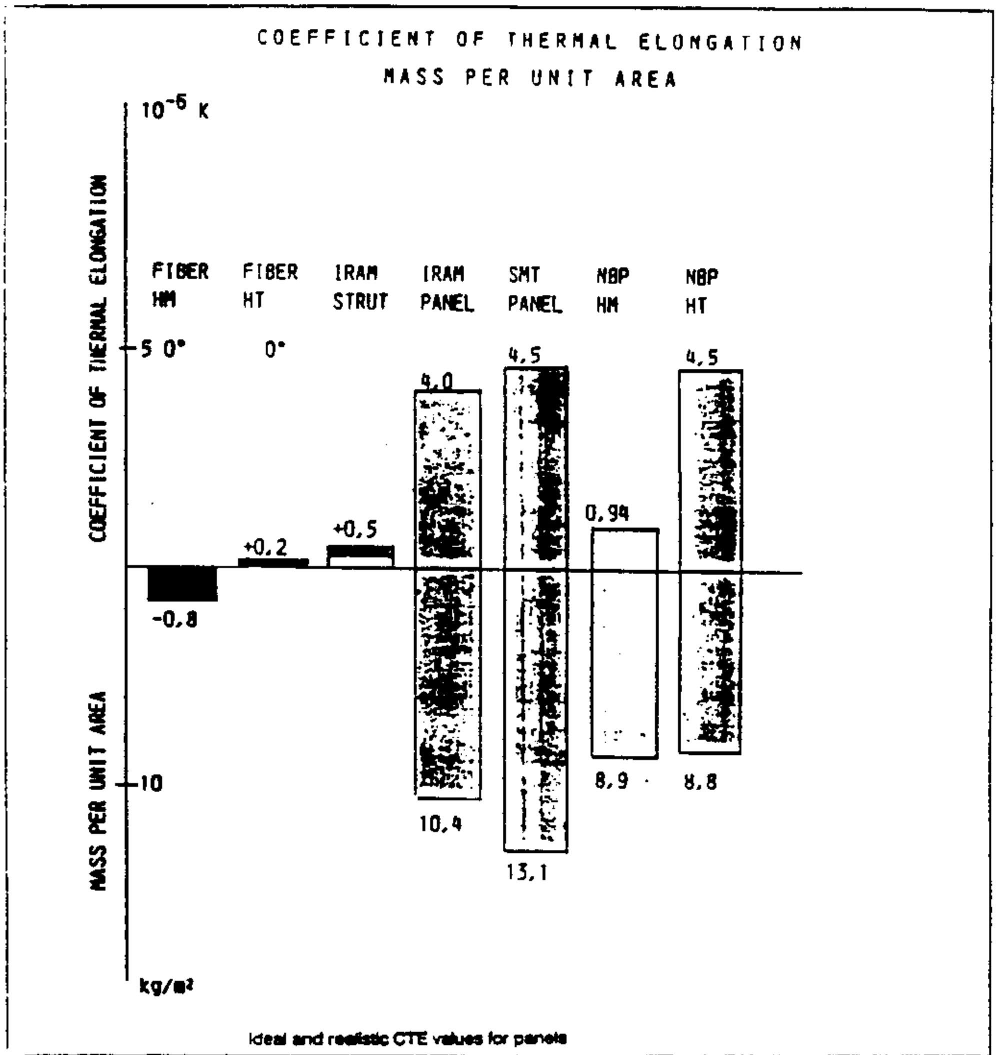


Fig. 2.46 Practical CTE

To complete the basic data values for thermal conductivity (CTC) are given. They show the low values under 90 °C fiber orientation - which is through the skin thickness and transvers across the skin area.

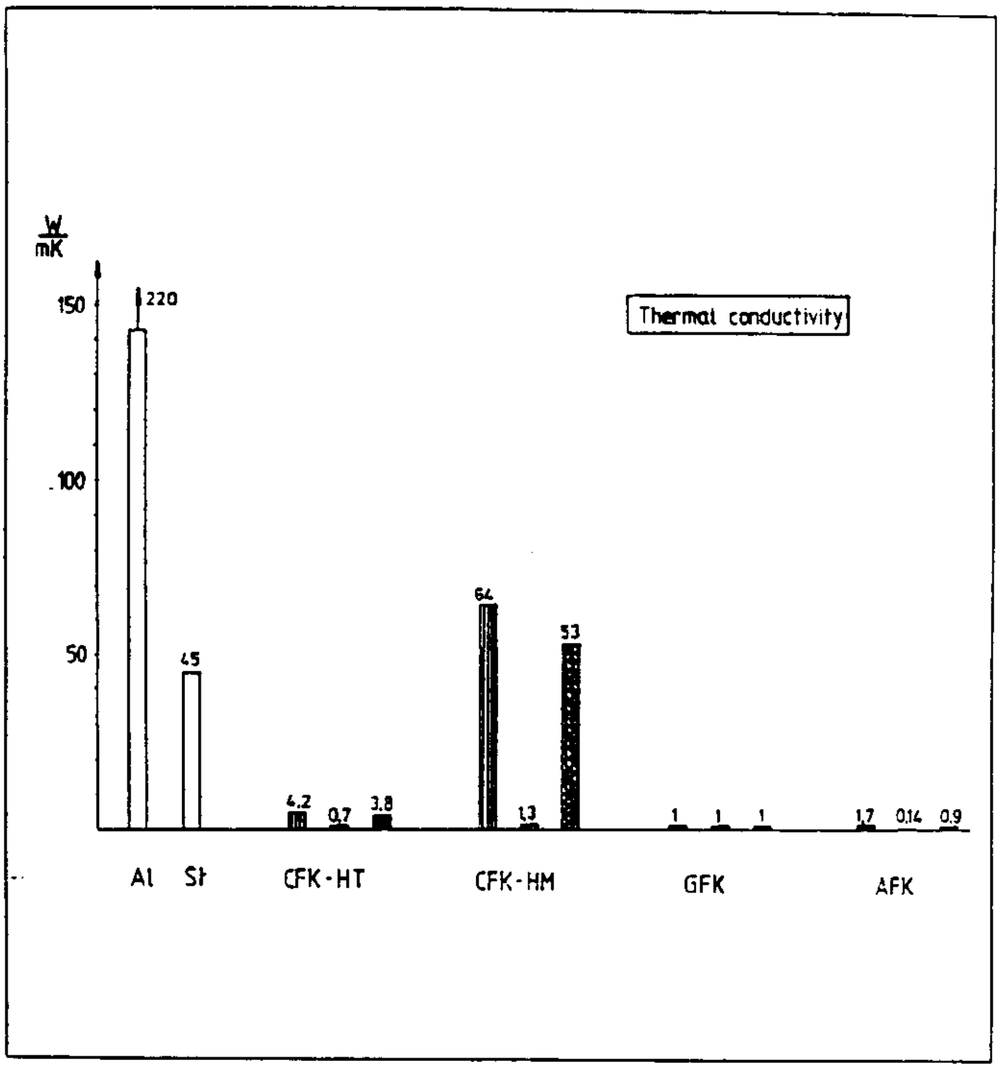


Fig. 2.47: Thermal Conductivity

To achieve a smooth temperature distribution between front and rear skin under changing temperatures the highest CTC will be used with the application of aluminium. In the sandwich core one may unhexagonal, overexpanded or flexcore honeycomb types. If the curvature of the panel is very low (as on SAO panels) standard hexagonals will be used for economic reasons and for the lowest difference of stiffness in both orientations.

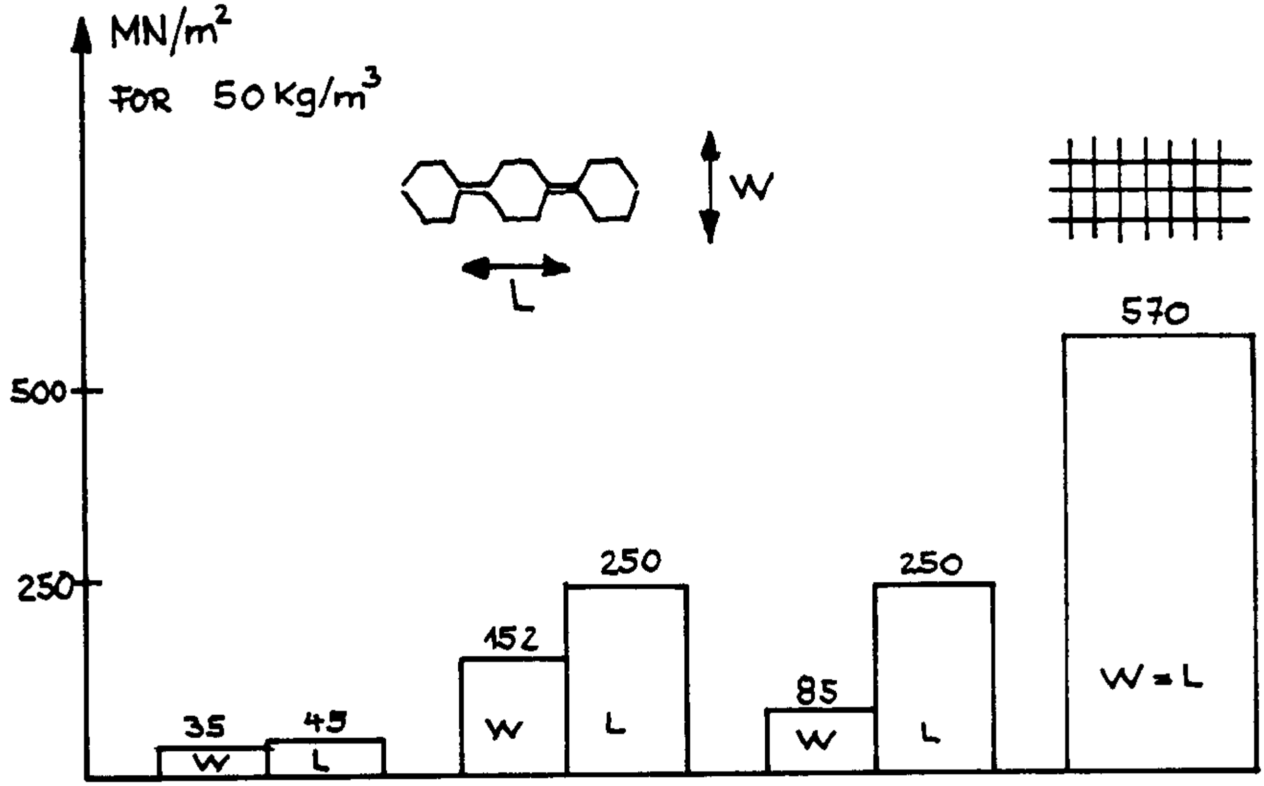


Fig. 2.48 Core stiffness comparison

RECOMMENDATION:

To improve the panel technology (stability, thermal deformation, temperature distribution) we recommend:

- high modulus biaxial carbon fiber laminate with
- hexagonal aluminium honeycomb core.

MOISTURE GAIN

This is the only performance of Cfrp panels where no real long time results are available due to the short time of practical exposure of Cfrp panels under operation.

The longest time are now at IRAM and SEST with app. 3,5 years practical operation under different environments.

No decrease in accuracy has been reported. The SEST telescope has been operated already at 0,6 mm wavelength, even when its design was for 1,0 mm.

Humidity results in an overall change of curvature (resp. focal length) which easily can be corrected. The moisture gain is related to different resin types and can be reduced by a special selection and more by a total coating with foil (SMT).

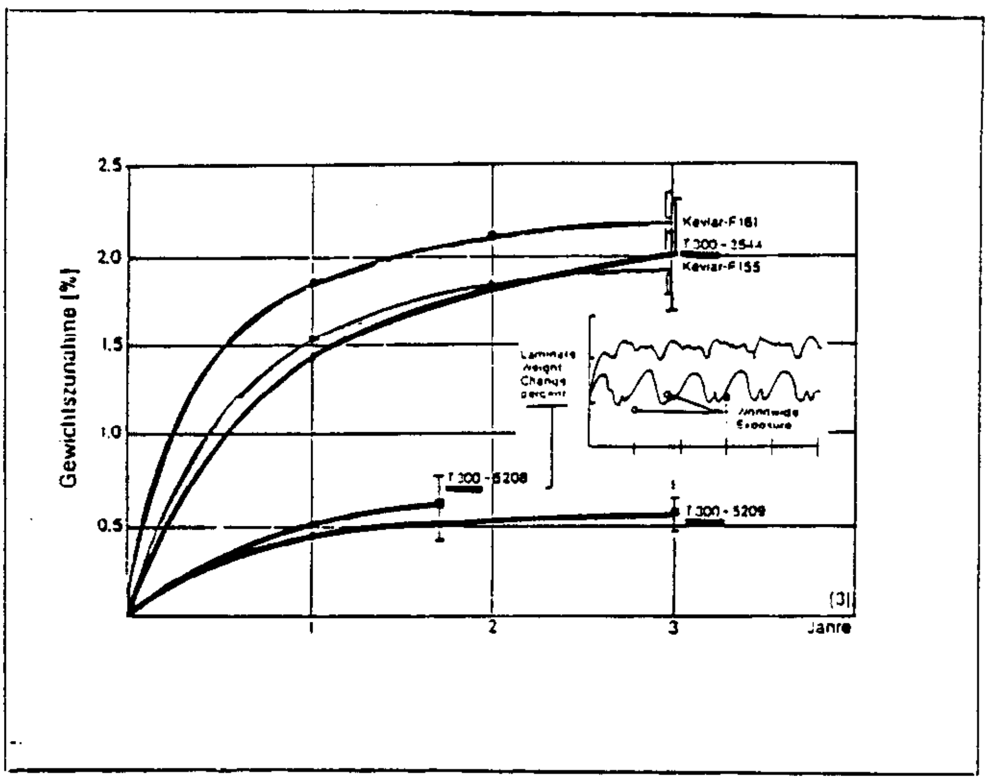


Fig. 2.49 Moisture gain

Besides the resin type the normal humidity of the environment and the absoulte temperature influence the maximum humidity gain as shown in Fig. 2.50.

A low humidity results in a 3 times lower gain than a high humidity. This low humidity is relevant for the exposure places of radiotelescopes.

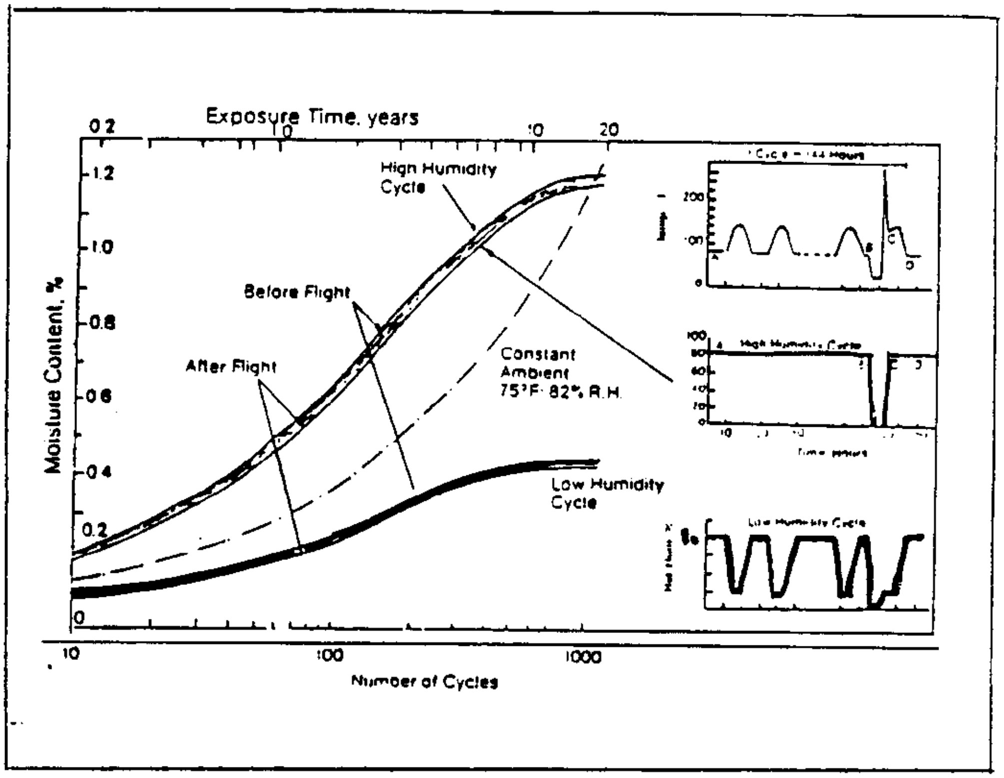


Fig. 2.50 Humidity gain under different exposures

MAN TECHNOLOGIE

SURFACE COATINGS

This materials have a large contribution to the characteristic of the panel. The main purposes are

- reflectivity of radio waves with lowest absorption,
- balanced absorptivity and emissivity for minimum temperature change during day and night for visible and infrared light,
- corrosion resistance,
- resistance against foreign object impact like stones, ice, hail.

Best reflectivity for radiowaves is given by bare metals, i. e. aluminium and Ni 36 alloys.

Other reflectivities are related to the wavelength and have to be measured for each special application of foil or coating on top of metal.

2.51 Absorption ESCO/GORE-TEX

2.52 ETFE Spray

2.53 ETFE Foil + 1 adhesive

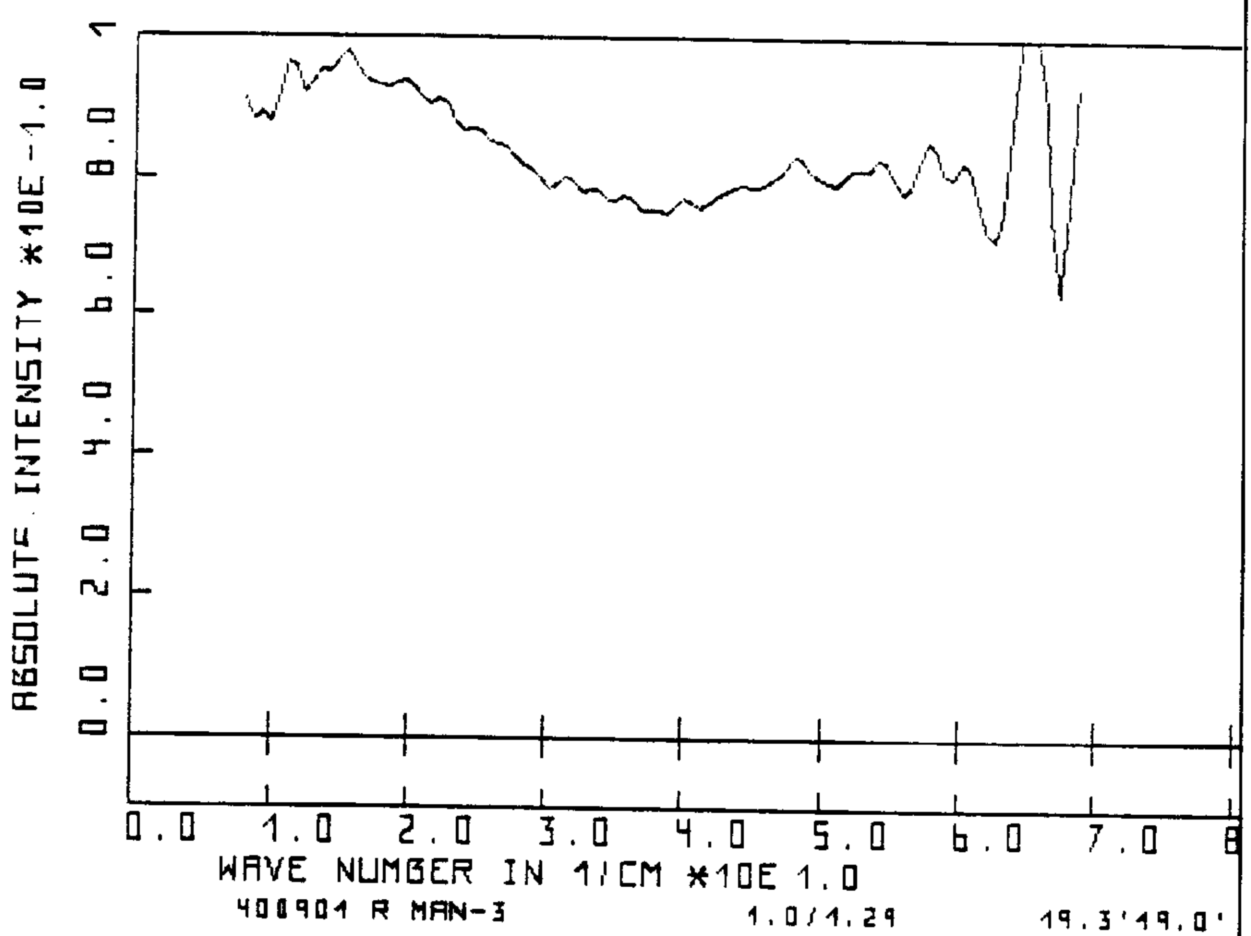
2.54 GORE-TEX bonded direct to Alufoil

The sensivity of mm waves to the unique thickness of the coating allows only very thin layers of foil and adhesives as their tolereances are in the range of 10 % of the absolute foil and adhesive foil thickness. Absolute tolerances of 10 µm allow therefore only foils with 100 mm thickness. These foils are normally (given by bad experiences) not humiditytight and free of microholes and corrsion is not absolutely prevented.

But as a protection coating of an aluminium foil with 40 µm thickness they are well applicable.

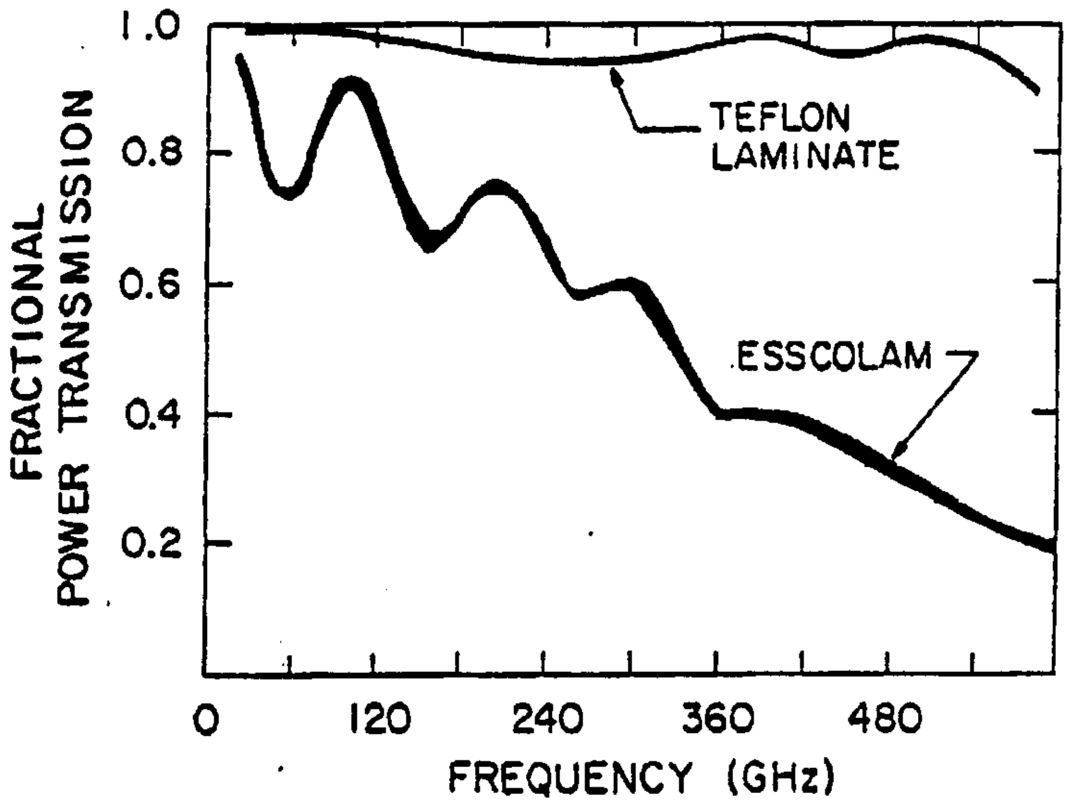
The corrosion resistance of aluminium can be achieved by eloxation but reflectivity, absorptivity and emissivity are pushed to the worse side. Ni 36 alloys have to be tested for corrosion, as no prooven data are available.

Smithsonian Astrophysical Observatory
Submillimeter Array
Reflector Study



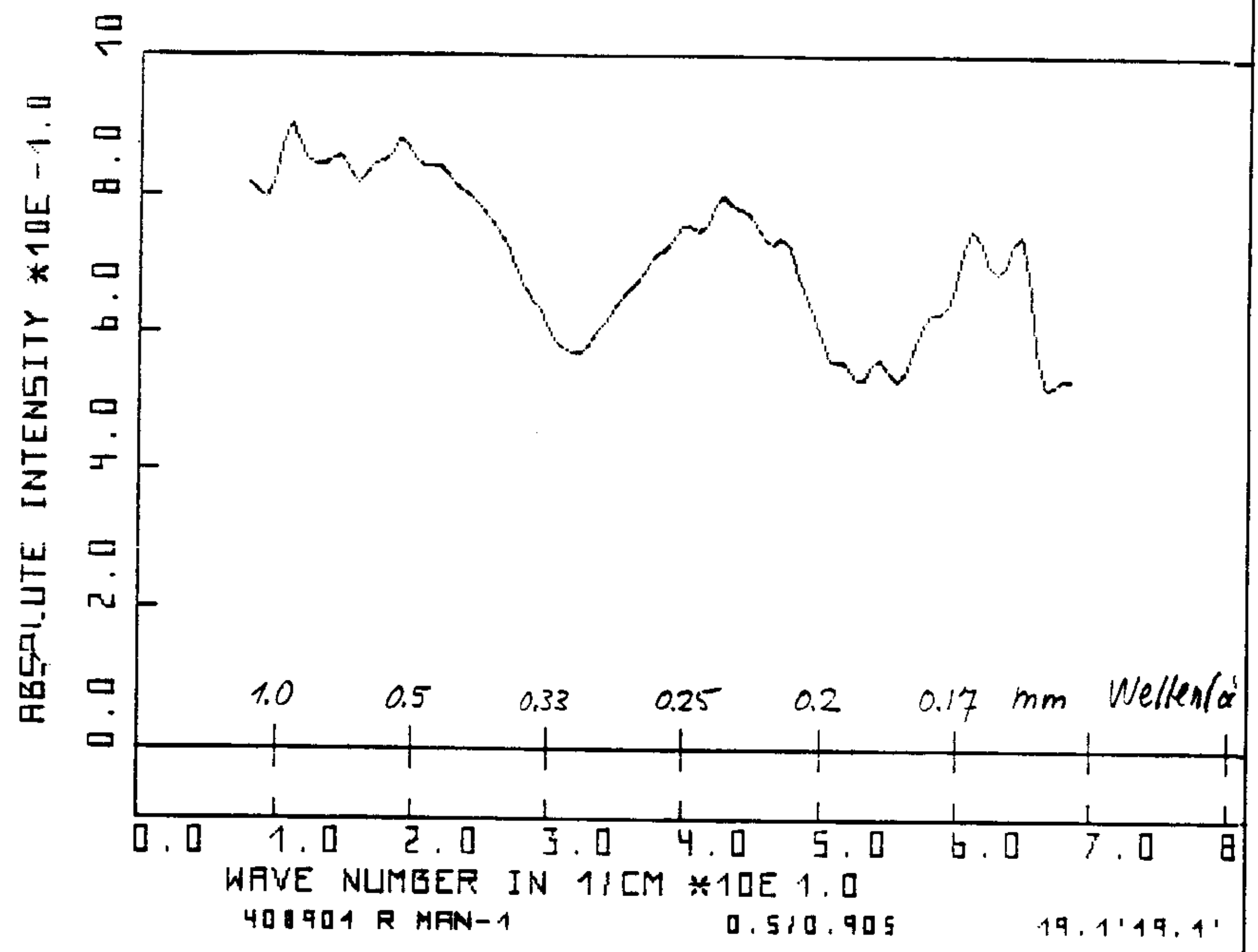
MATERIAL: ETFE
SPRAYED
THICKNESS APP. 3 µm

RL, 04/90 - vo



MATERIAL: GORETEX
THICKNESS UNKNOWN

Smithsonian Astrophysical Observatory
Submillimeter Array
Reflector Study

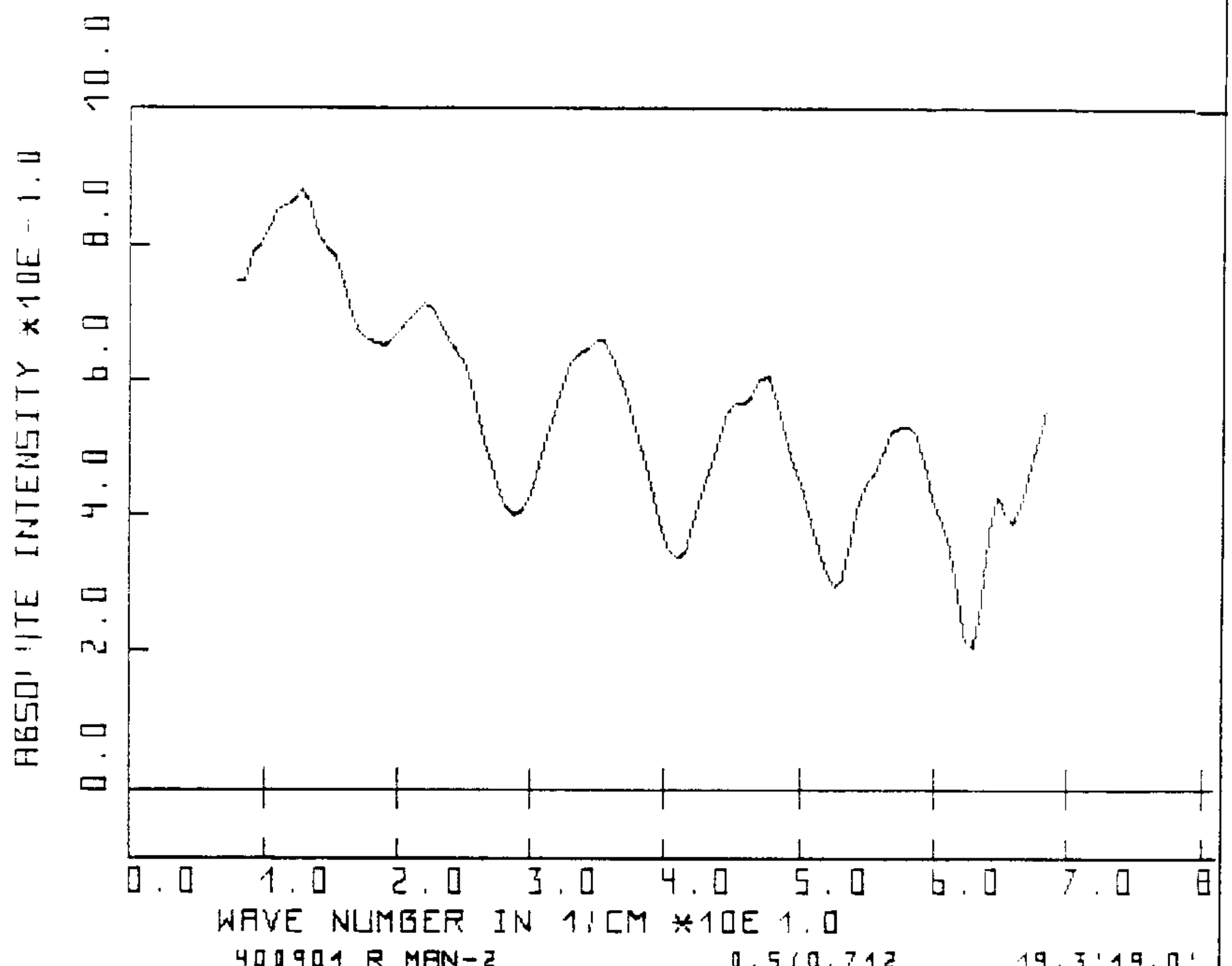


MATERIAL: ETFE
THICKNESS: 80 µm + 45 µm ADHESIVE

RL, 04/90 - vo

Fig. 2.51

Smithsonian Astrophysical Observatory
Submillimeter Array
Reflector Study



MATERIAL: ETFE
THICKNESS: 2 x (80 µm + 45 µm ADHESIVE)

RL, 04/90 - vo

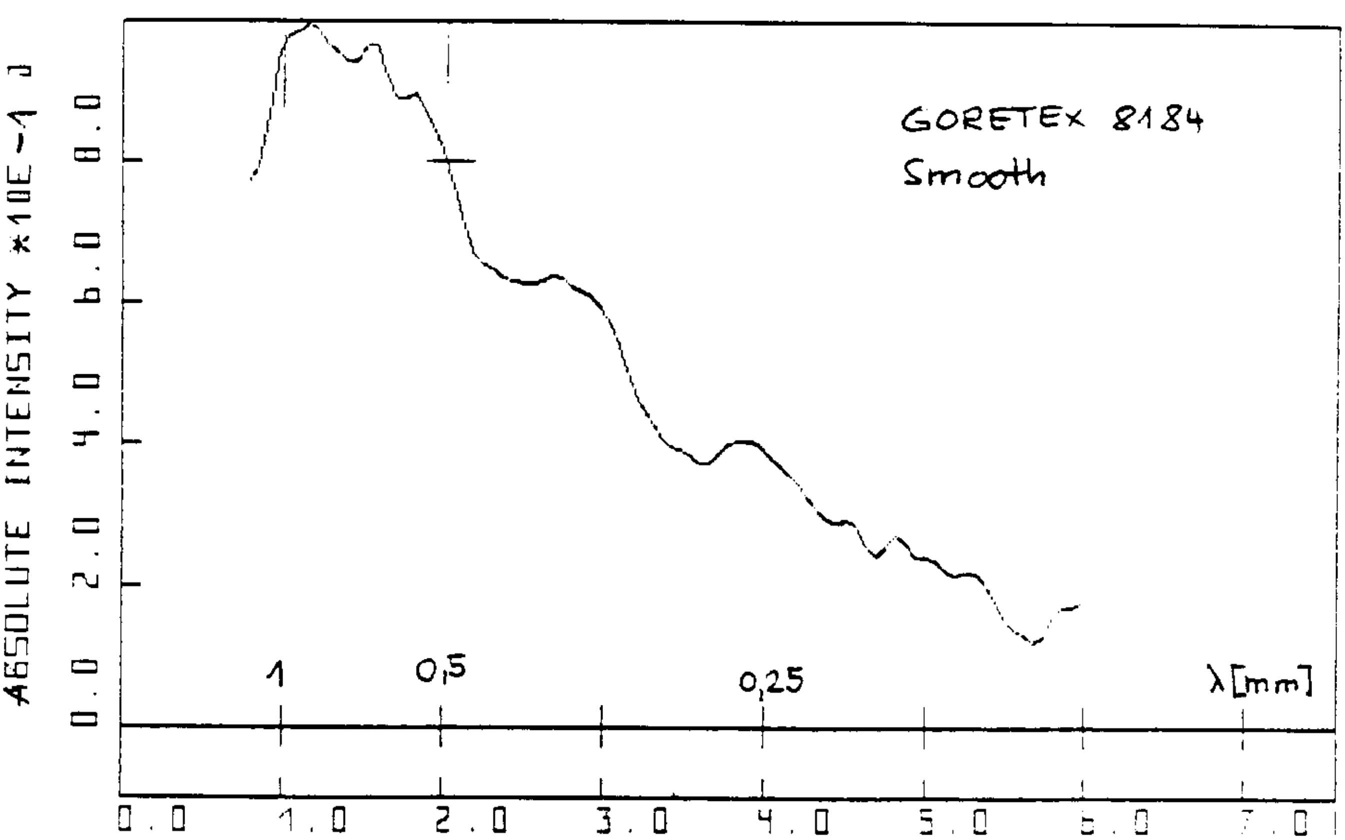
Fig. 2.52

REFLECTION MEASUREMENTS IN SUBMM-REGION ON REFLECTOR SAMPLES

The measurements were done with a broad-band Fourier-Spectrometer. The experimental setup allows reliable measurements at wavelengths below 1 mm. The sharp drop in the curves at 1 mm is an instrumental effect. All results are compatible with a reflection coefficient of essentially **one** at a wavelength of 1mm. The reference is a thick gold film, evaporated onto a plane Silicon-wafer.

The results are summarized in the following Table. The full measurements are shown in the attached Figures. Note that the horizontal scale is in wavenumber in units of cm^{-1}; thus 1.0 represents 1 mm wavelength and 4 is equivalent to 0.25 mm wavelength. The sample designation is written under each curve.

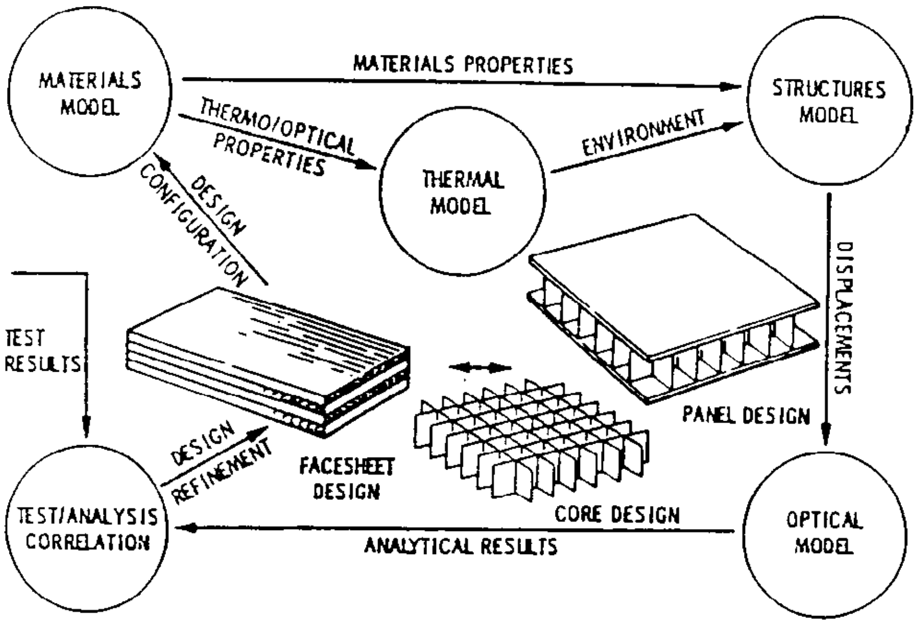
Sample designation	**Reflectivity** λ = 1 mm	**Reflectivity** λ = 0.5 mm
1. Goretex 8184, smooth on Alu	1.0	0.80
2. Goretex 8185, smooth on Alu	1.0	0.80
3. Goretex 8184, rough on Alu	1.0	0.85
4. Goretex 8184, smooth on Alu	1.0	0.74
5. Pure Aluminium	1.0	1.0
6. Aluminium with Hostaflon	1.0	0.88



3.1 Analysis of Panels

3.1.1 Optimisation process

Fig. 3.1 shows a flux diagram concerning the optimization process of a sandwich panel. Well to be seen here is the interaction between modelling, design, analysis and test/analysis correlation.



Optimizing Process for Sandwich Panel

3.1.2 Tools for calculation

The tools for conceptual reflector and panel design are computer programs based on analytical methods like plate theory and laminate theory for composite structures.

For design verification FEM calculation methods are used.

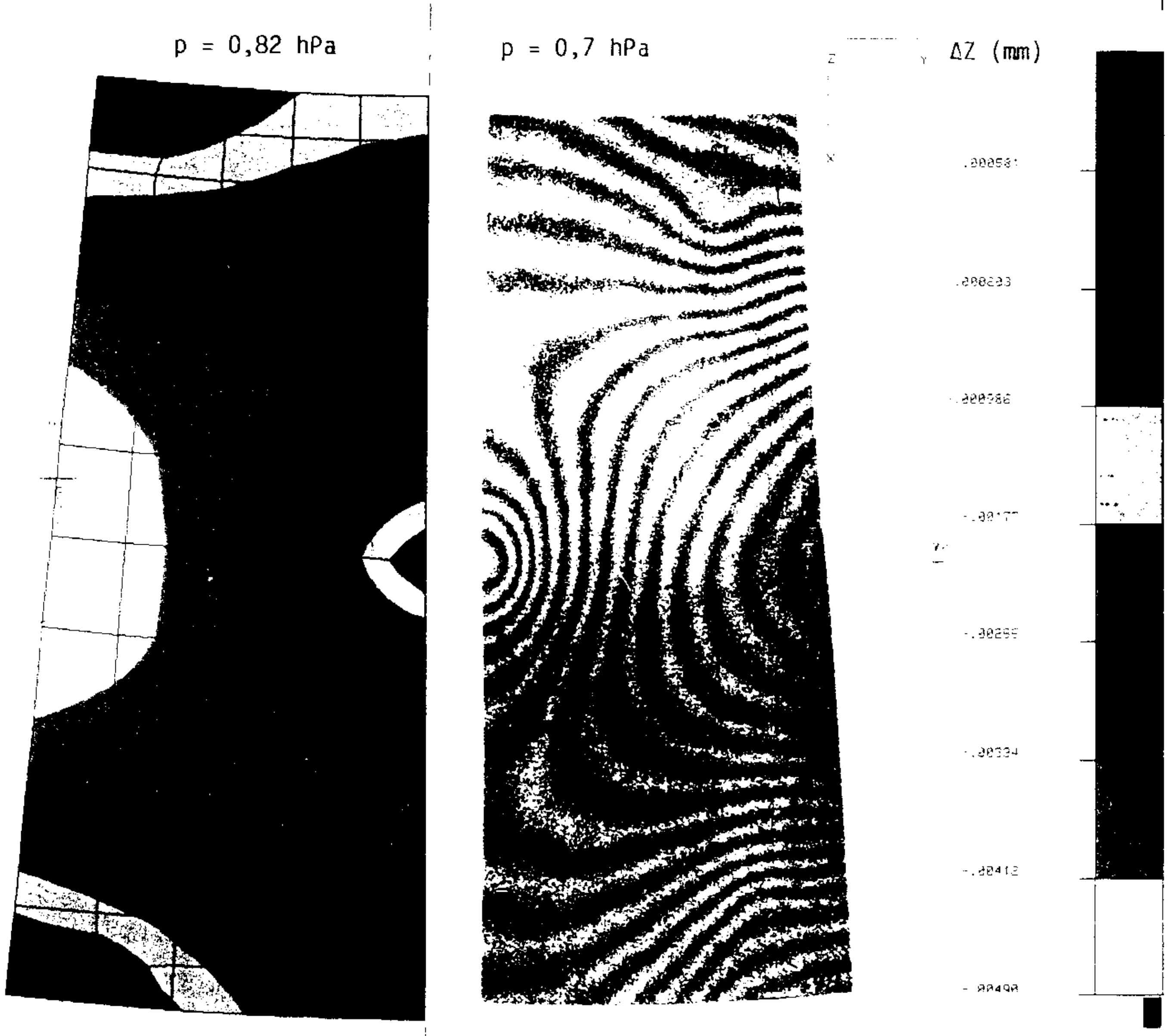
At MAN Technologie the tool for FEM panel analysis is the NASTRAN program. FEM meshing and presentaion of will be done by the PATRAN pre- and postprecessing program.

During the qualification phase of the IRAM and SMT panel the NASTRAN results were controlled by holographic measurements under mechnical and thermal loading

Figures 3.2 to 4 show some examples of the comparison between FEM (left) and

Smithsonian Astrophysical Observatory
Submillimeter Array
Reflector Study

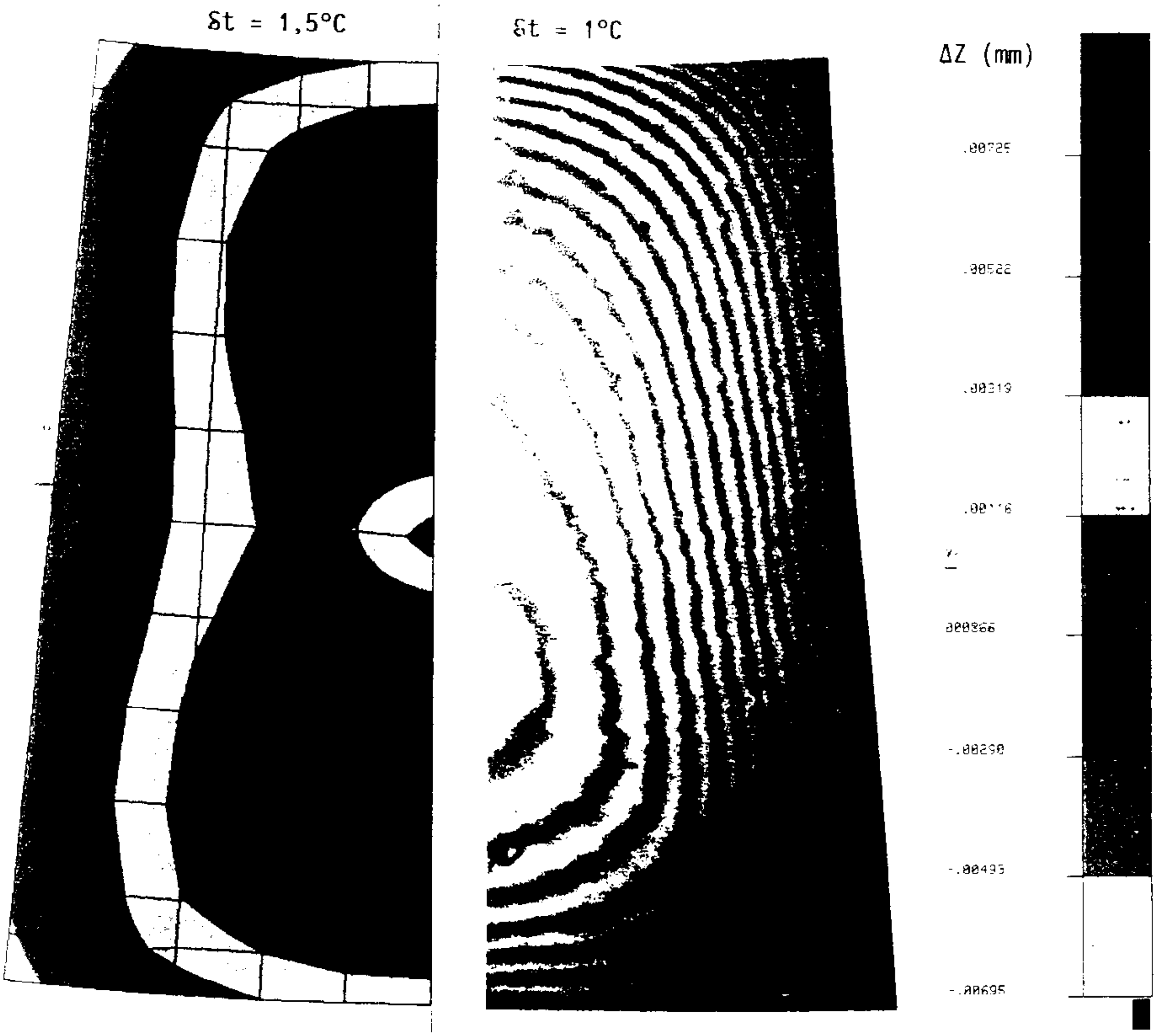
PANEL QUALIFICATION (IRAM 4)



WIND LOAD: NASTRAN AND HOLOGRAPHY

Fig. 3.2

PANEL QUALIFICATION (IRAM 4)

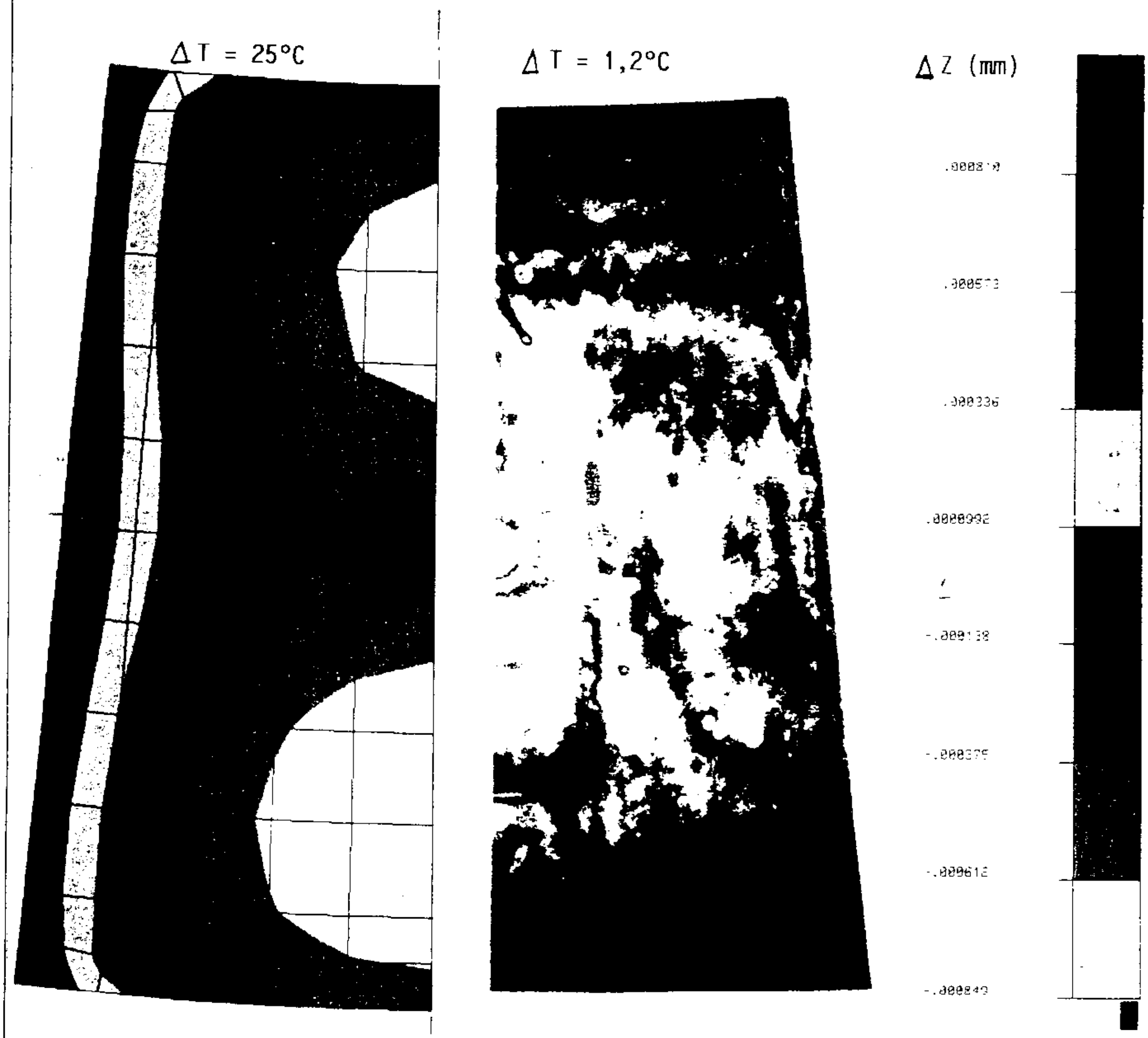


INTERNAL TEMPERATURE DIFFERENCE (FRONT ./. REAR)

Fig. 3.3

Smithsonian Astrophysical Observatory
Submillimeter Array
Reflector Study

PANEL QUALIFICATION (IRAM 4)



ABSOLUTE TEMPERATURE CHANGE

Fig. 3.4

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3.1.3 Examples of FEM-calculation results

Fig. 3.5 presents the FEM in-plane deflections of the SMT panel. Its asymmetry arises from the asymmetric attachment of the panels to the reflector trusswork.

On table 3.1 are listed the calculated values of the SMT panel for rings 1, 2, 3 and for a 30-degree sector of the reflector.

Two kinds of best fit calculations were done:

- Panel Shifting: Motion of the panel parallel to focus axis (rms-z).
- Focal shifting: Calculation of a new theoretical parabola. The contour deflection was compared with the new parabola, with calculation of the focal shifting (delta f).

Version	Lastfall	Wind 102,6 N/m²	Δ T = -20°C (+20°C)	δT = 2,5°C	g zenit	g90° vertikal
		rms (µm)	rms (µm)	rms (µm)	rms (µm)	rms (µm)
	Soll	2	3	6	2	2
186 GL	rms Δ z	1,2	5,5	5,2	2,0	3,9
	rms-z	0,5	1,0	4,4	0,5	0,1
	rms-f	0,5	0,9	4,2	0,5	0,1
	Δ f	0,0	-15,0 (15,0)	50,7	0,4	-1,9
287 GL	rms Δ z	2,0	19,6	7,0	4,8	6,7
	rms-z	1,0	2,0	5,2	1,0	0,2
	rms-f	0,9	1,5	5,0	0,9	0,2
	Δ f	8,2	22,9	-20,4	9,1	-0,1
387 GL	rms Δ z	2,7	50,9	5,2	15,6	20,2
	rms-z	1,4	0,8	6,2	1,1	1,1
	rms-f	1,3	0,8	6,0	1,0	1,0
	Δ f	37,1	-2,5	20,6	6,5	-3,4
30°-Sektor SMT GL	rms Δ z	2,2	36,2	5,9	10,8	14,1
	rms-z	1,6	1,7	6,4	1,2	1,5
	rms-f	1,1	1,3	6,2	0,9	1,1
	Δ f	8,0	6,5	-11,7	5,5	6,9

A panel attachment perpendicular to the surface gives the best result for the panel accuracy under operation This qualitativity shown in Figure 3.6.

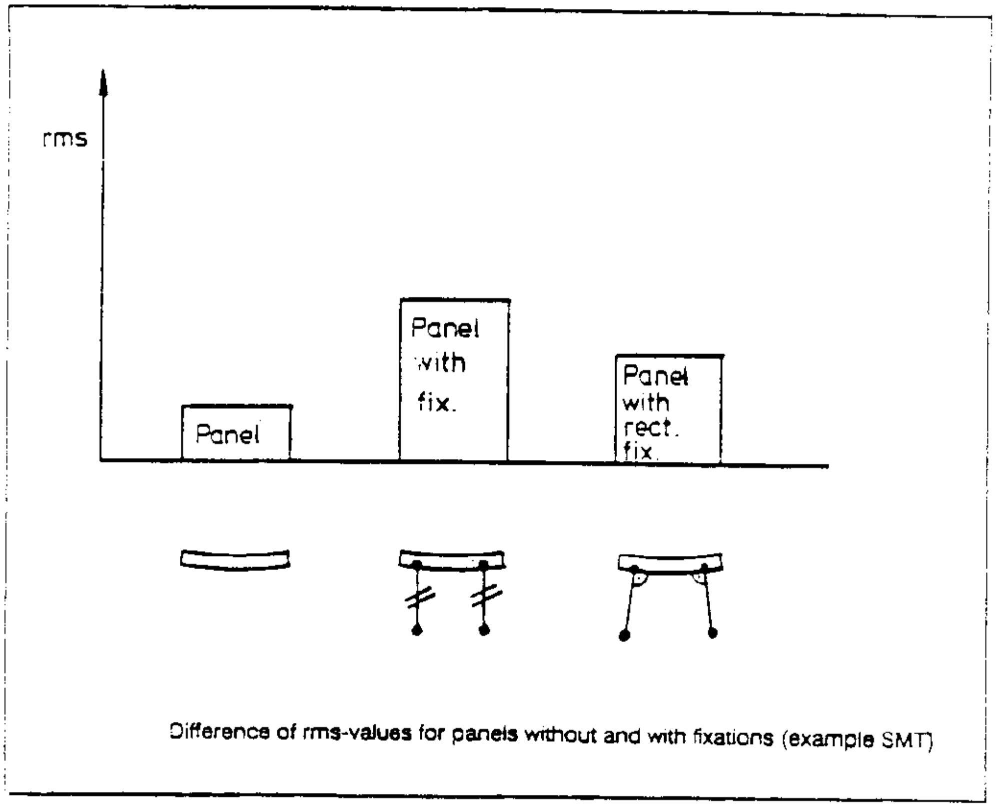
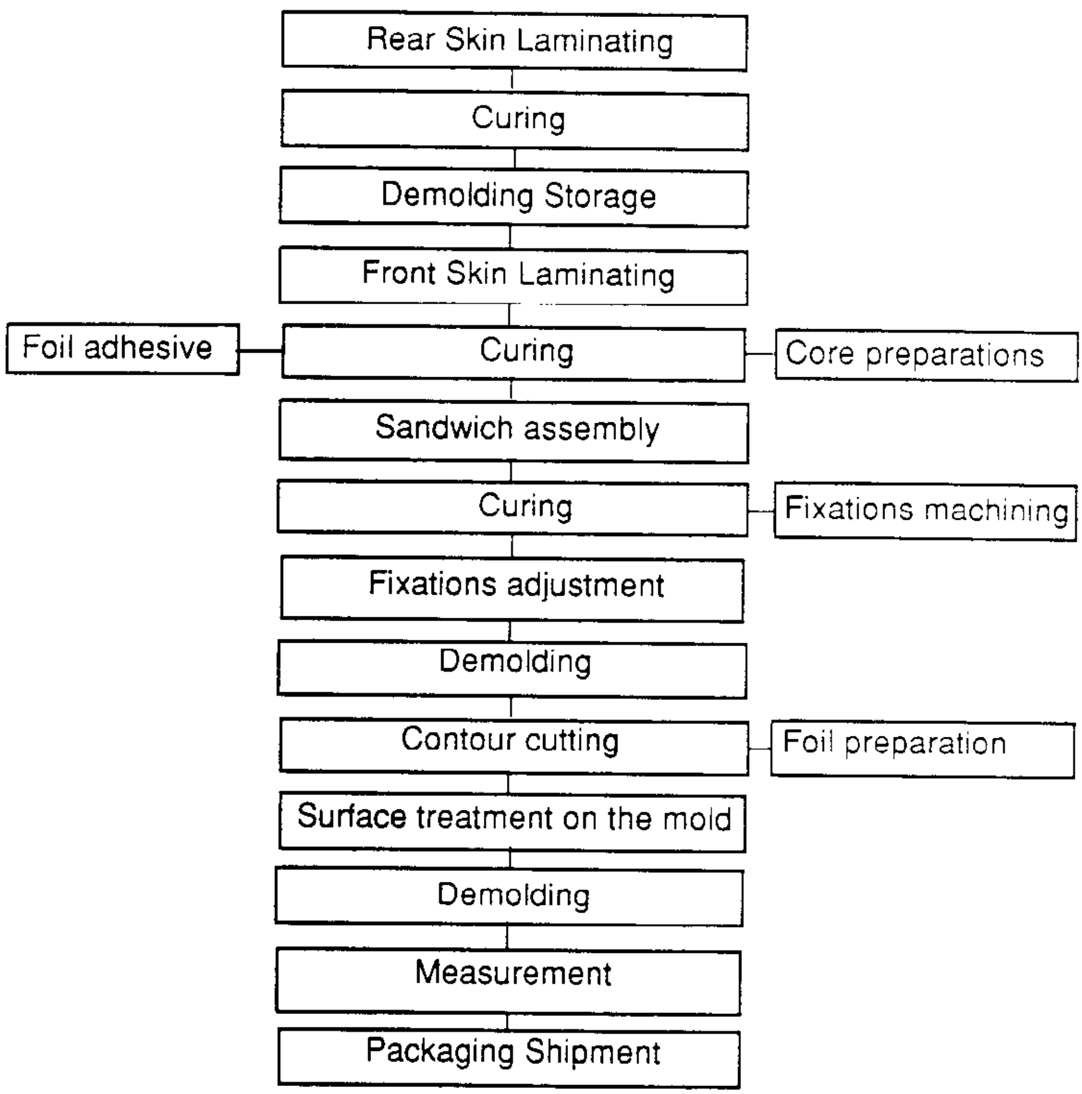


Fig. 3.6

All the results and the experience of MAN show, that a high accuracy reflector can be made in Cfrp with full conficence into the results given by analysis and test.

3.2 Panel manufacturing

Principle basis for the manufacturing of serial panels is the following diagram:



This flow chart shows the main principles:

Two shot process with

- cured skins
- prepared core

Final accuracy on the mold with patented MAN-replica process and

- reflecting foil or alternative
- mold coated with reflecting layer or
- uncoated mold.

For this final solution an auxiliary vacuum deposition of the reflective coating is necessary and without problems possible. To achieve the reflecting surface MAN has tested all solutions. For minimizing the mold breakage risk the reflecting foil is the optimum solution but better thermal behaviour of the panel is reached by the two other ways.

- CTE of the mold close to the CTE of the panels.

If high modulus skins and core are required, the use of Zerodur or ULE molds is necessary ($CTE < 0{,}316 \cdot 10^{-6} K^{-1}$) to reduce the internal stresses during the curing process (used for PRONAOS).

- Both skins of the panel with the same curvature require only one mold and give parallel core contours.

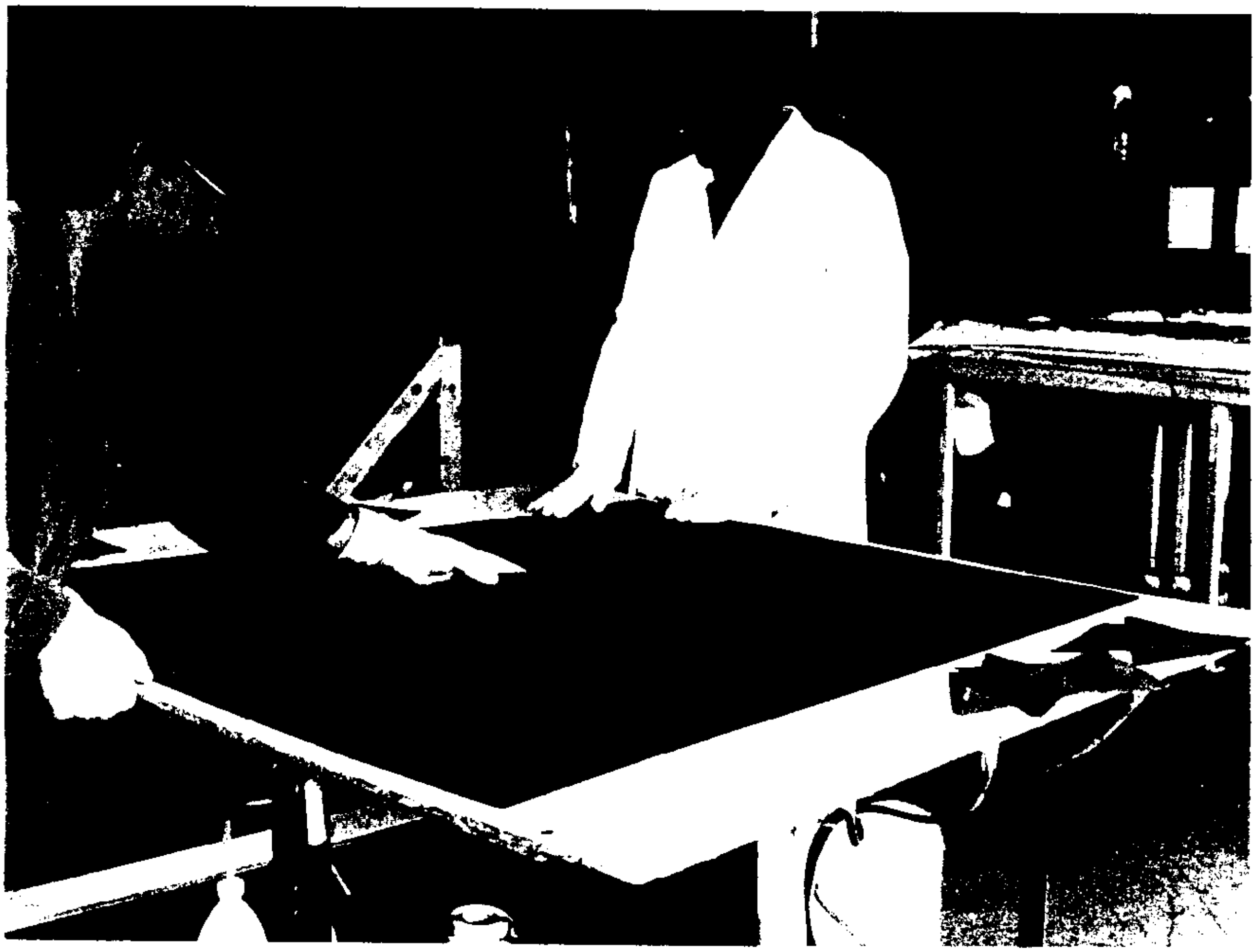
The experiences of MAN with this processes already used in the programs IRAM, SMT, PRONAOS and Lasermirror gives the advantage of only minor modifications for any other precision mirror program. Refinements are necessary caused by

- type and curing process of cfrp-prepreg
- type and conductivity mold
- accuracy of panel contours
- type and orientation of fixations

All other fabrication, handling and quality assurance measures are already well established, qualified and applicable for SAO panels.

The following pages show the hardware production of Cfrp panels.

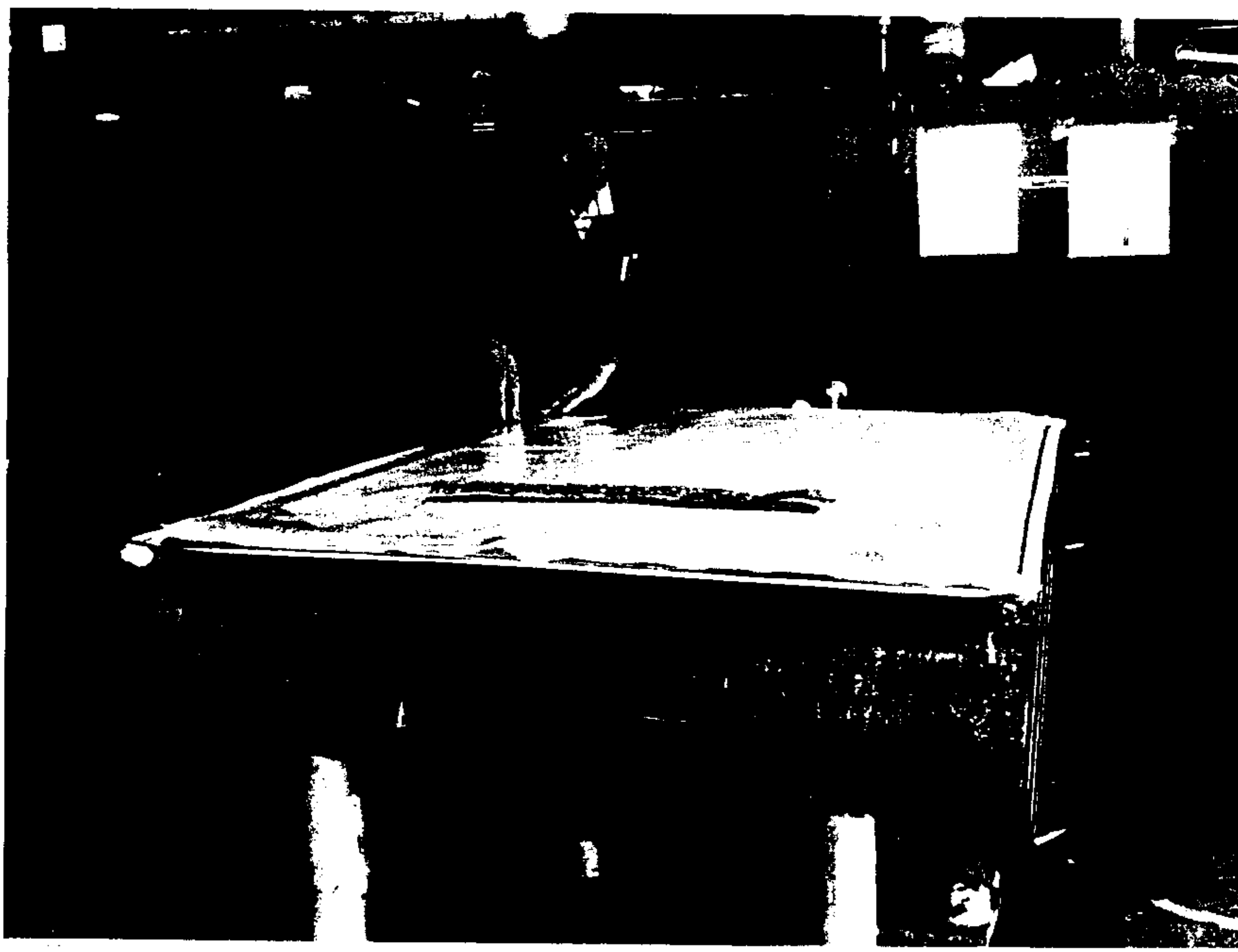
MANUFACTURING OF RADIOTELESCOPE-PANELS



PREPREG POSITIONING

Fig. 3.7

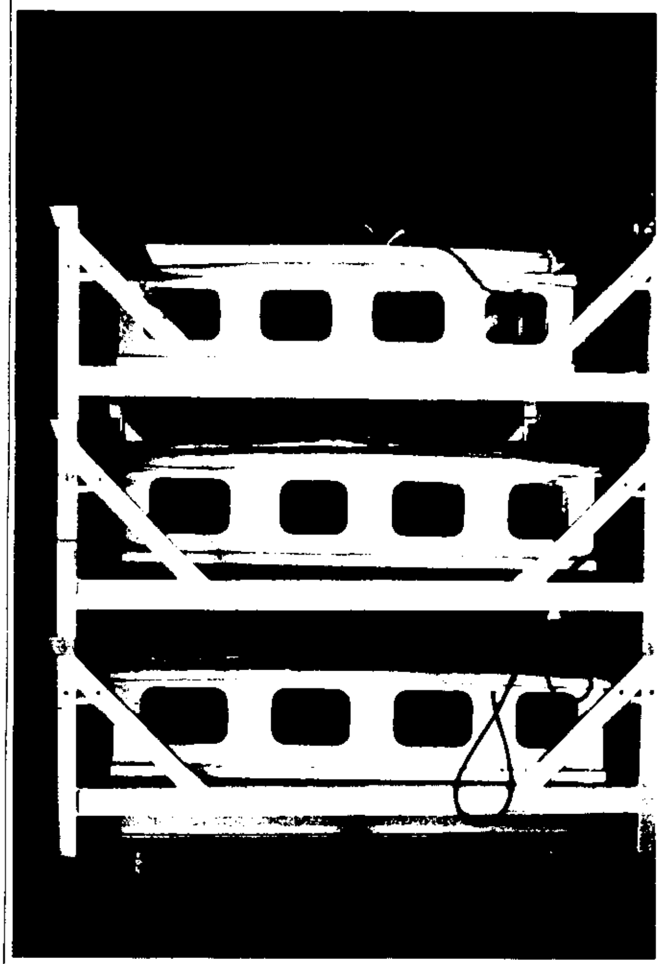
MANUFACTURING OF RADIOTELESCOPE-PANELS



VACUUM BAG PREPARATION

Fig. 3.8

MANUFACTURING OF RADIOTELESCOPE-PANELS



CURING UNDER VACUUM IN OVEN

Fig. 3.9

AUTOCLAVE TECHNOLOGY MANUFACTURING OF SANDWICH PANELS FOR RADIO TELESCOPES

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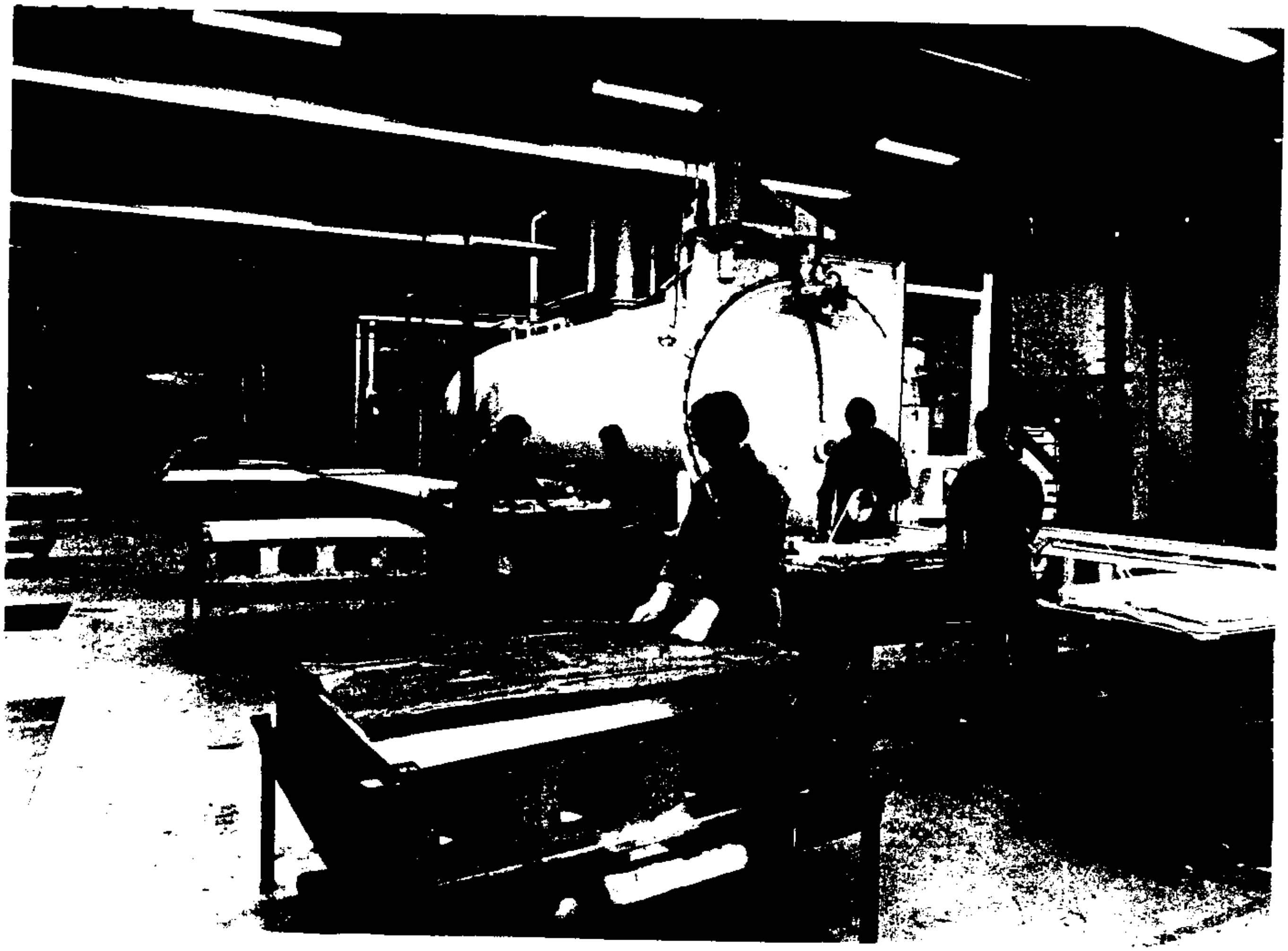


Length max.	8000 mm
Diameter max.	2500 mm
Temperature	250°C
Pressure	1,5 MPa

RL/7116-1-1/88/PEIF2

MANUFACTURING OF RADIOTELESCOPE-PANELS

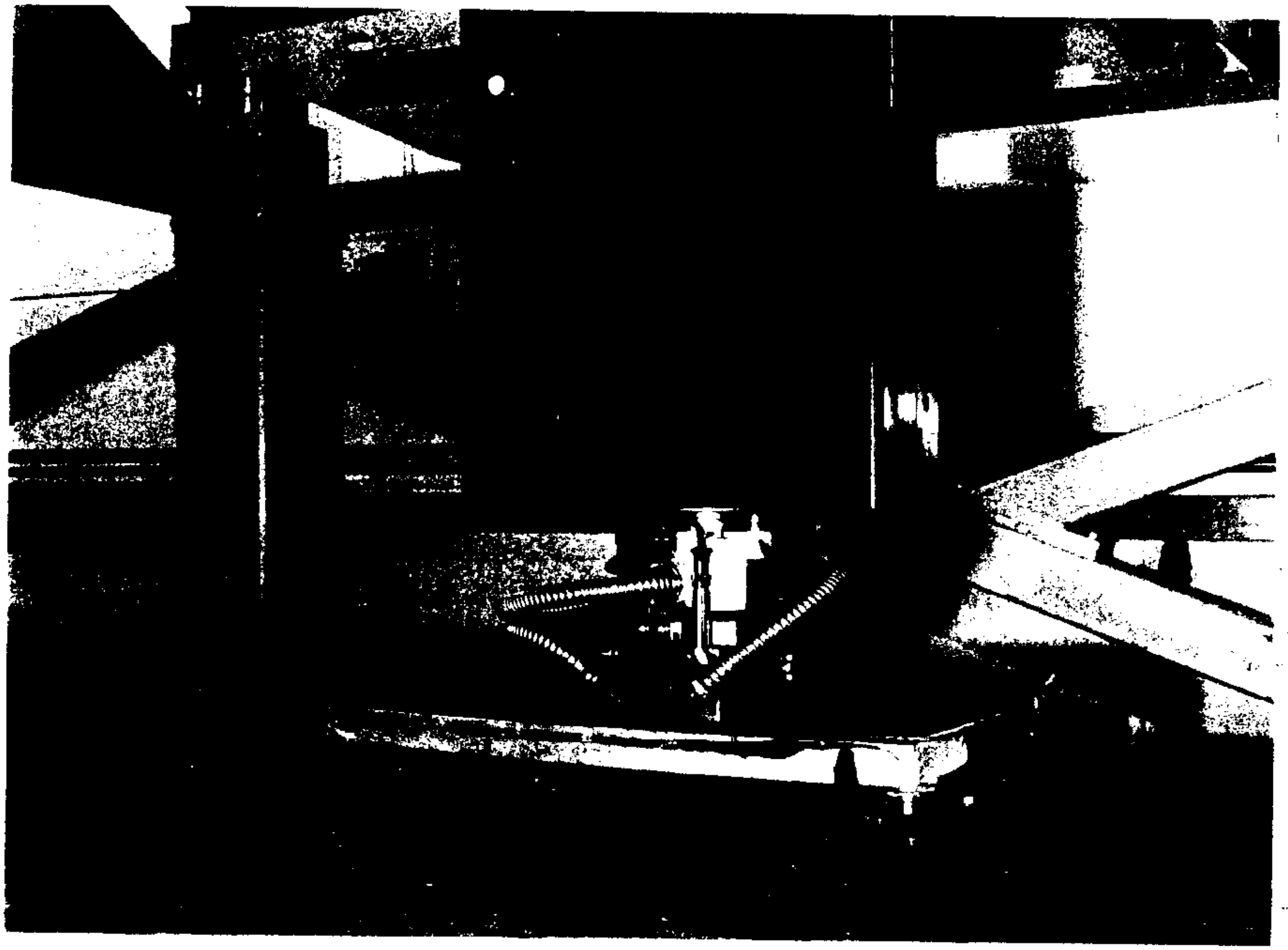


Fig. 3.10

Cutting area:	50 m²
Max. size:	2,5 x 2 x 0,8 m
Equipment:	4-axis numerical controlled cutting machine
Pointing accuracy:	0,2 mm
Cutting speed:	60 cm/min
Vaccum cleaner with dust filter	

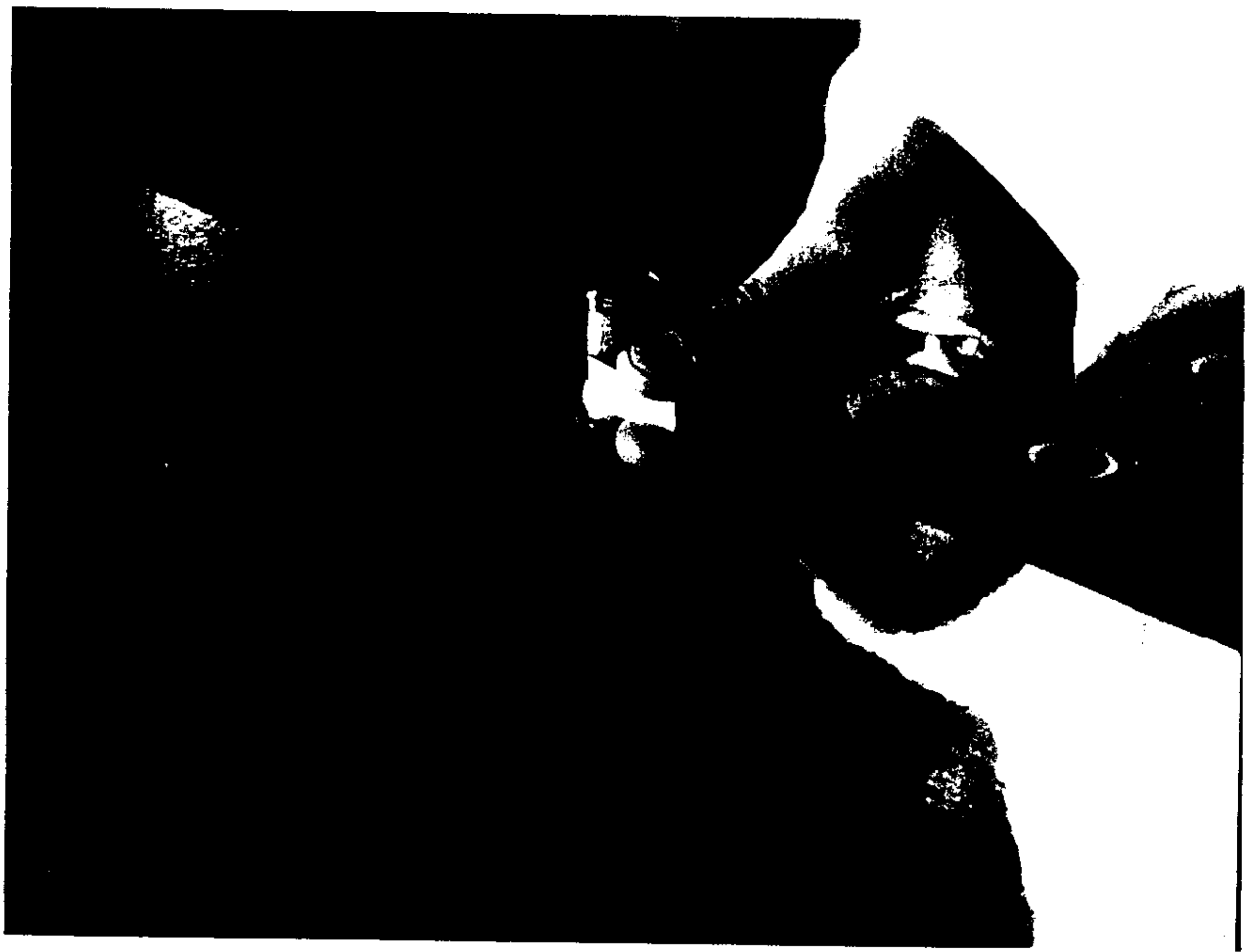
MANUFACTURING OF RADIOTELESCOPE-PANELS

FOIL COATING ON PRECISION MOLDS
5 - 8 µm rms

Fig. 3.11

MANUFACTURING OF RADIOTELESCOPE-PANELS

QUALITY CONTROL

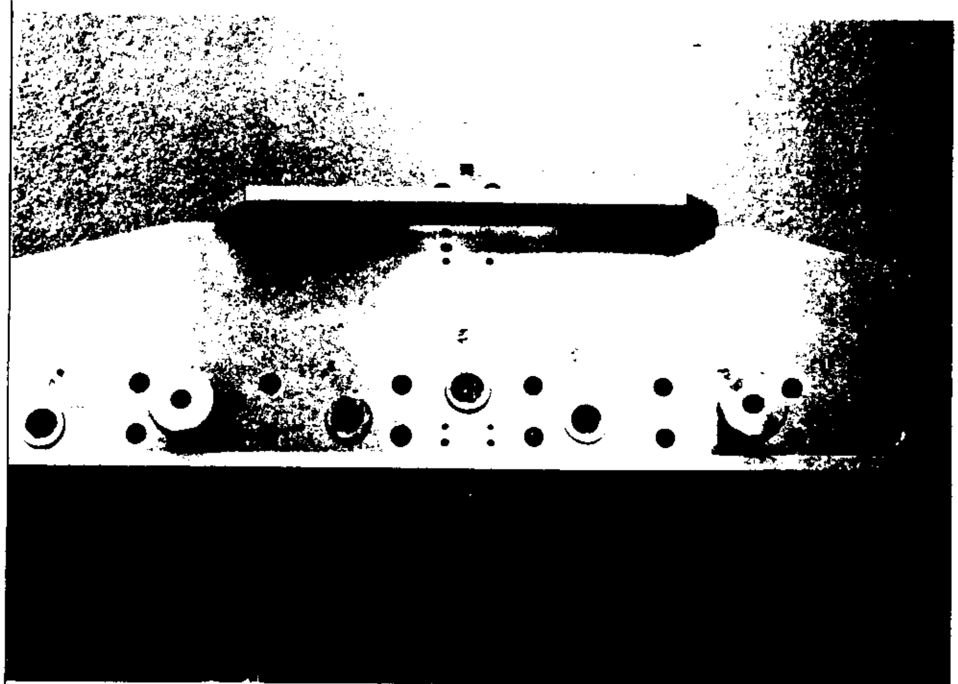


CONTOUR MEASUREMENT

Fig. 3.12

MANUFACTURING OF RADIOTELESCOPE-PANELS

SURFACE CONTROL
ACCURACY 1 µm



CONTROL JIG BALANCE
FOR 3 POINT FIXATION

For the required qualification or the development of new coatings, fixations or other specialities all methods and installations are available at MAN Technologie or instiutions in the neighborhood.

- natural fequencies	Fig. 3.14
- reflectivities – thermal / radioastronomical	
- icing and deicing in nature and simulated cooling chamber tests	Fig. 3.15
- outdoor lifetime exposure	Fig. 3.16
- surface temperature	Fig. 3.17
- deformations under loads and temperature	Fig. 3.18
- mechanical surface measurement of surface roughness	Fig. 3.20
- preassembly and mechnical measurement of surface	Fig. 3.19

Qualification of Radiotelescopes

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STRUCTURE TESTS

NATURAL FREQUENCY
OF IRAQ-M2

RL, 06/90

Qualification of Radiotelescopes

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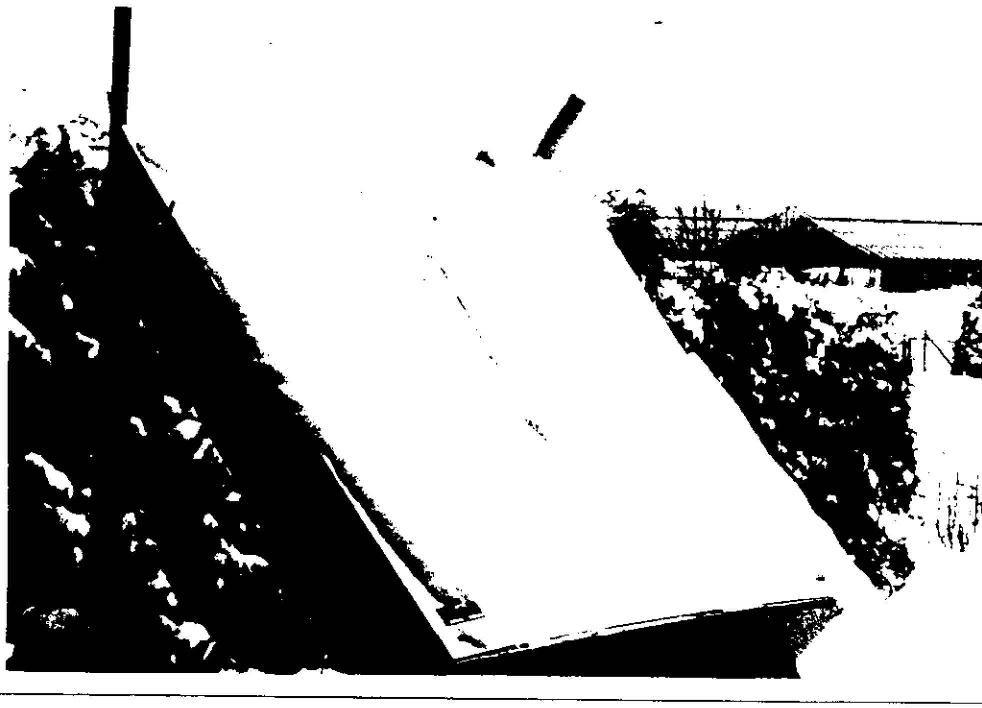
PANEL DEVELOPMENT

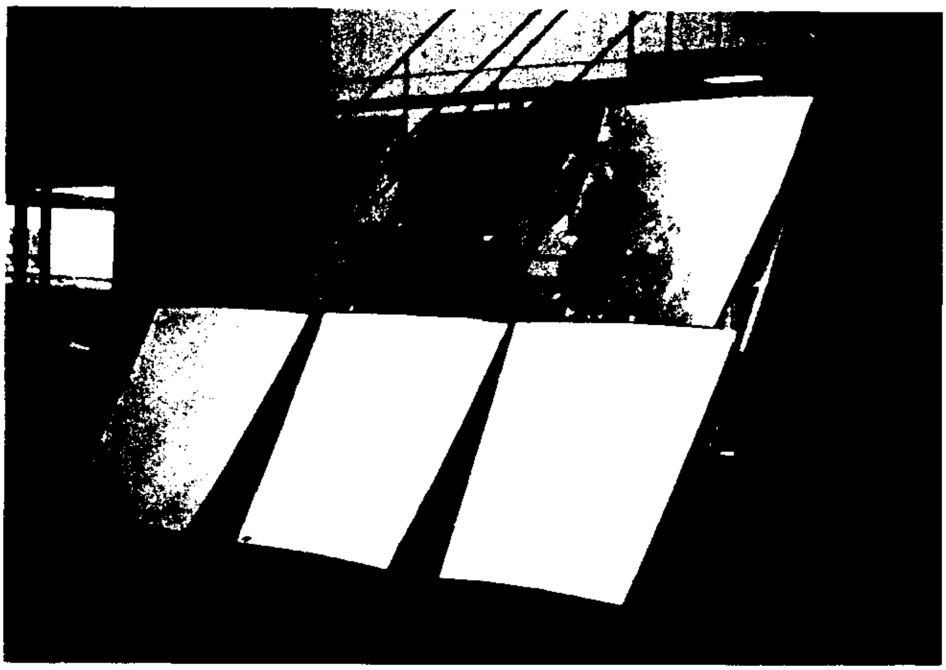


DEICING SYSTEM
NATURAL TEST

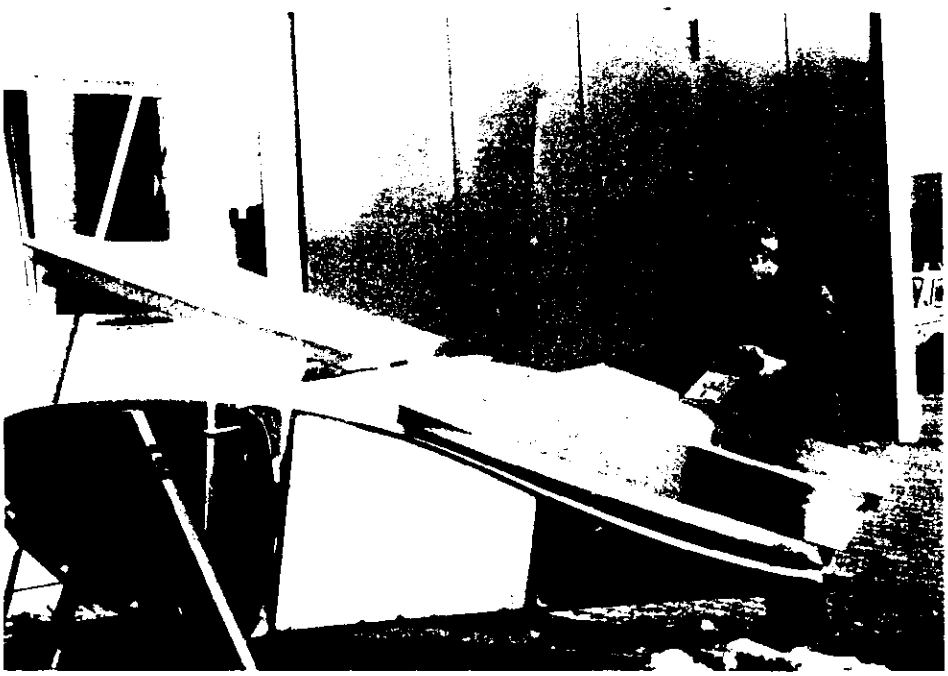
RL, 06/90

Qualification of Radiotelescopes

PANEL DEVELOPMENT



OUTDOOR TEST RIG



SURFACE TEMPERATURE

RL, 06/90

Qualification of Radiotelescopes

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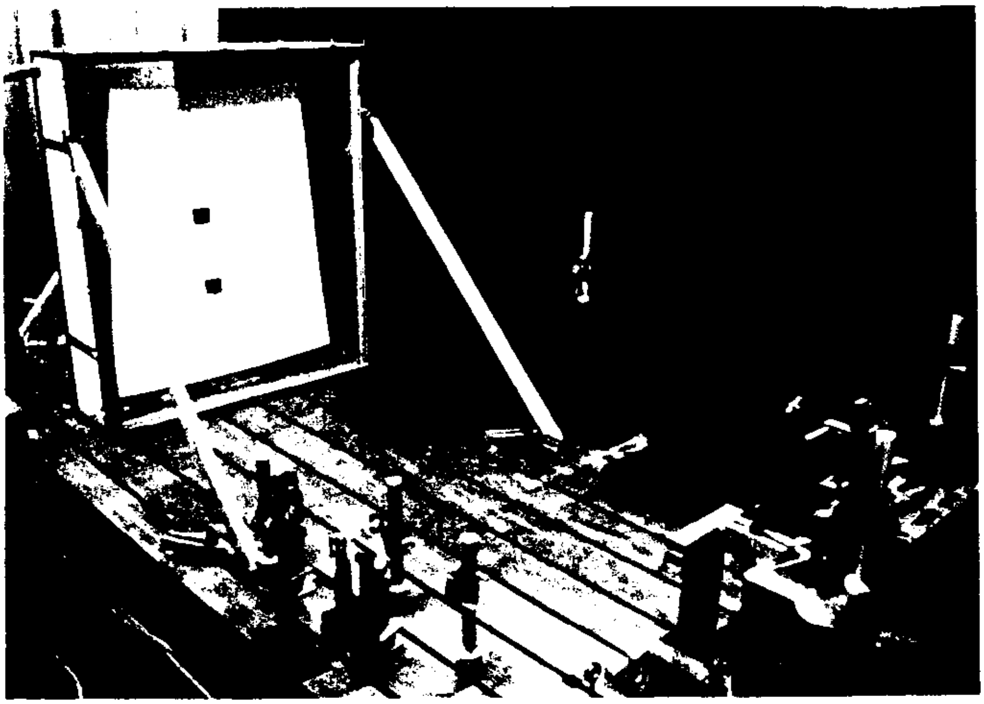
PANEL QUALIFICATION



HOLOGRAPHIC TEST SET UP

INTERNAL TEMPERATURE DIFFERENCE TEST

RL, 06/90

Qualification of Radiotelescopes

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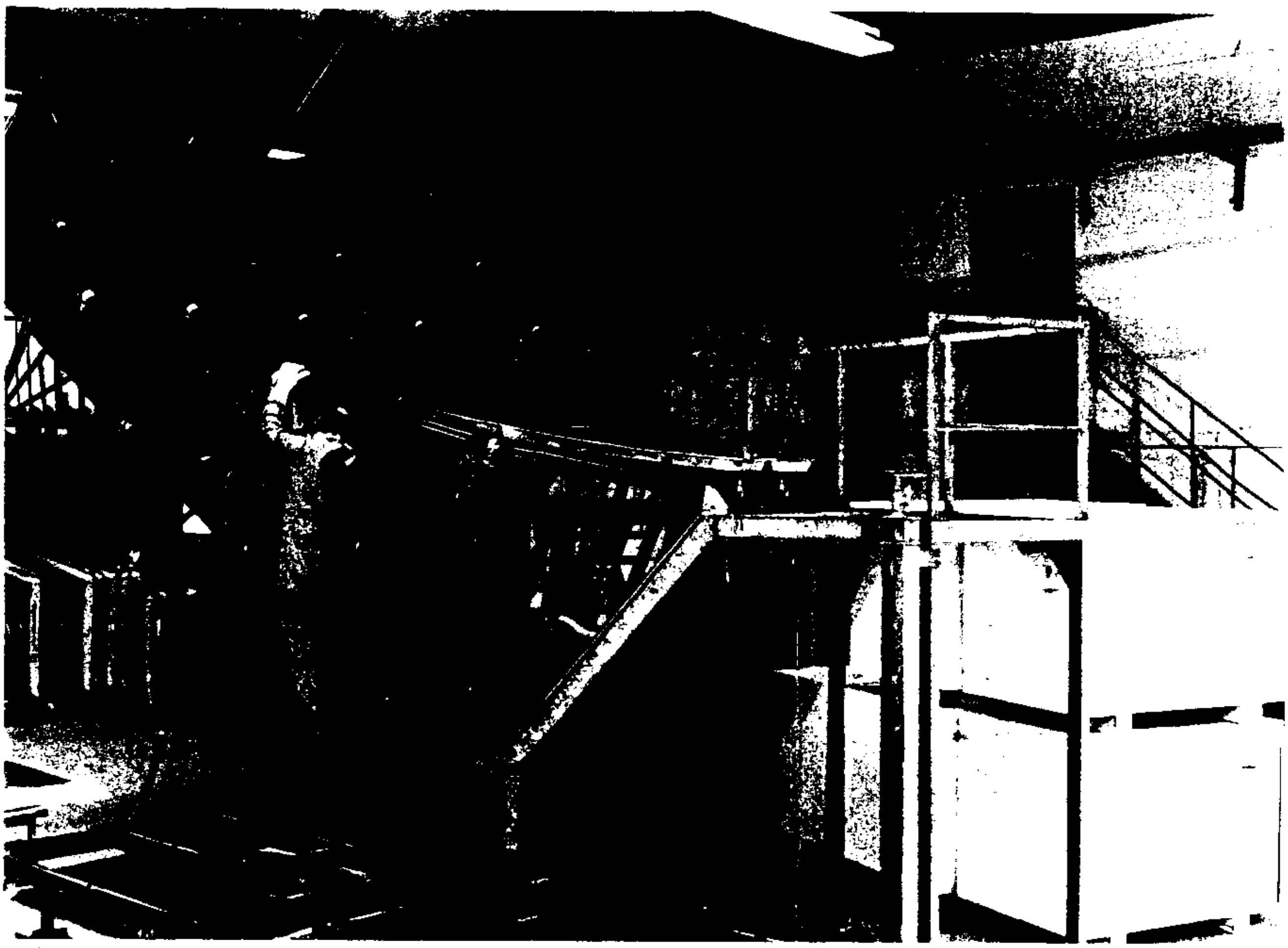
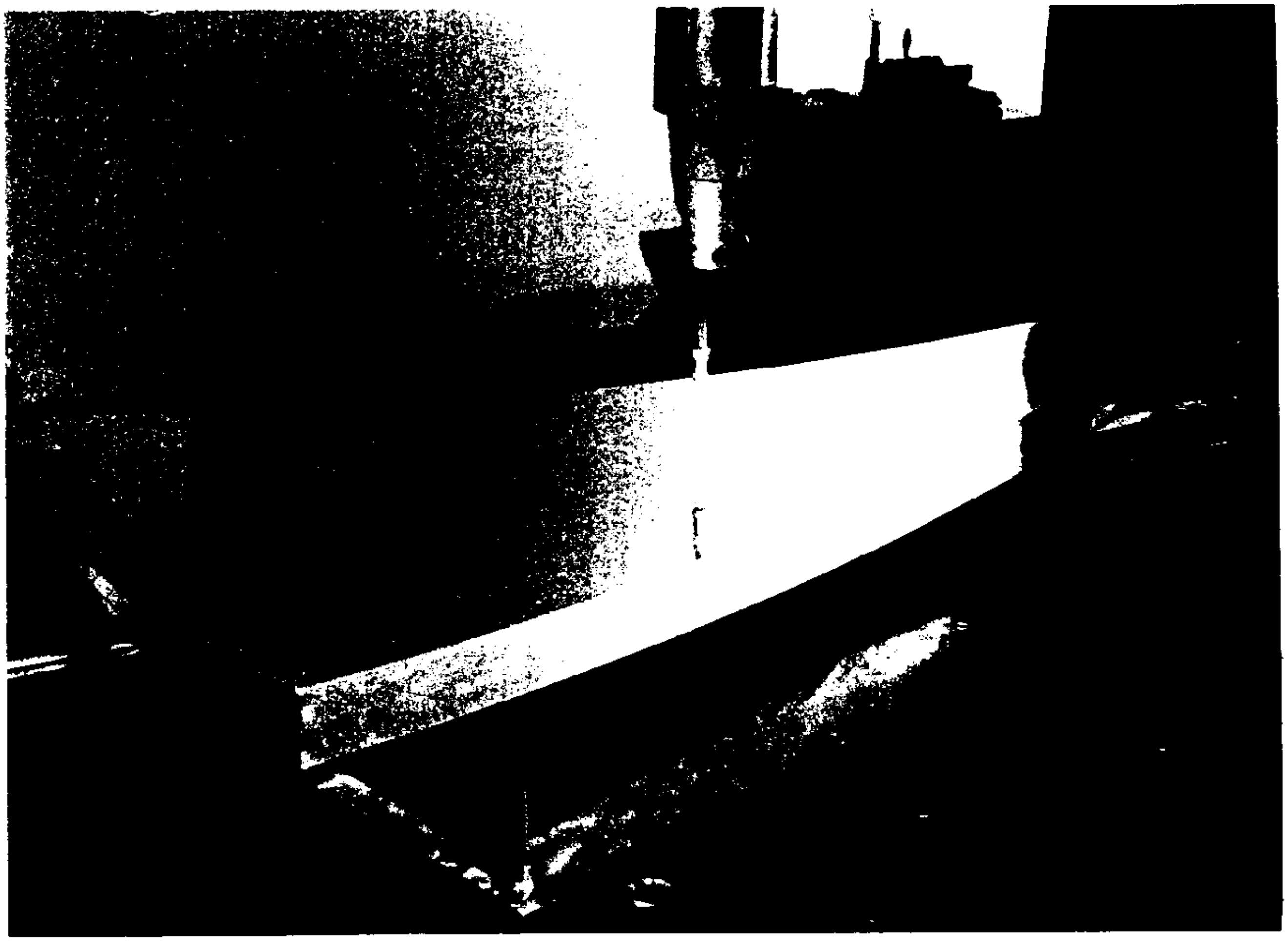
TEST ASSEMBLY AT MAN WORKSHOP



MEASUREMENT OF A CFRP-PANEL FOR THE SUBMILLIMETER TELESCOPE - SMT -

MAN TECHNOLOGIE



Panel data:

Length:	1,850 mm
Width:	1100 mm
Supporting:	5 points
Supporting for measurement:	3 points

3.3 Comparison of results

Comparing all the results from former analysis and manufacturing it will be possible to realize a submillimeter array to the desired goals. Panel size is in the range of already built telescopes, accuracies have already been reached with standard panels in Cfrp technologies. All tools for analysis and design are available, prooven and can be used for design of SAO array.

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4. Costs

With the experiences of different types of reflectors budgetary curves can be given for all phases of reflector development and manufacturing.

Following the time schedule and manufacturing flow following costs have to be elaborated:

Definition study

- definition of reflector
- definition of surface coating
- test panel

Design

- design
- analysis
- prototype panel

Manufacturing

- molds
- jigs
- panels
- work preparation
- quality assurance

Assembly

- reflector structure
- panel adjustment

Testing

- surface coating
- qualification test with different loadcases under holography
- prototype assembly
- natural frequencies of dish
- stiffness of dish

Developping an array with more than three antennae it is wise to build high performance molds and tools. They reduce the total cost of program.

All costs are budgetary and will be elaborated in detail for the next phase.

4.1 Definition study

The definition study must include following work packages:

- final definition of loadcases
- maximum allowable deformations
- definition of back up structure
- definition of panels
- evaluation of surface coating with a test panel (made on any available mold)
- test report

The total cost of this study is estimated to

DM 250.00,--

With these diagrams the area costs for molds with 3 μm rms are

steel: 170.000 DM/m²

glass: 310.000 DM/m²

Detailed prices will be given by possible suppliers in the next phase. For the real mold areas this gives for 2,4 m²

steel: 410 KDM and

glass: 750 KDM per set of molds.

TOOLING COSTS

To assemble the sandwich panel, to drill and bond the fixations and to cut the panel shape some more tools are necessary. The budgetary costs are given in Fig. 4.2

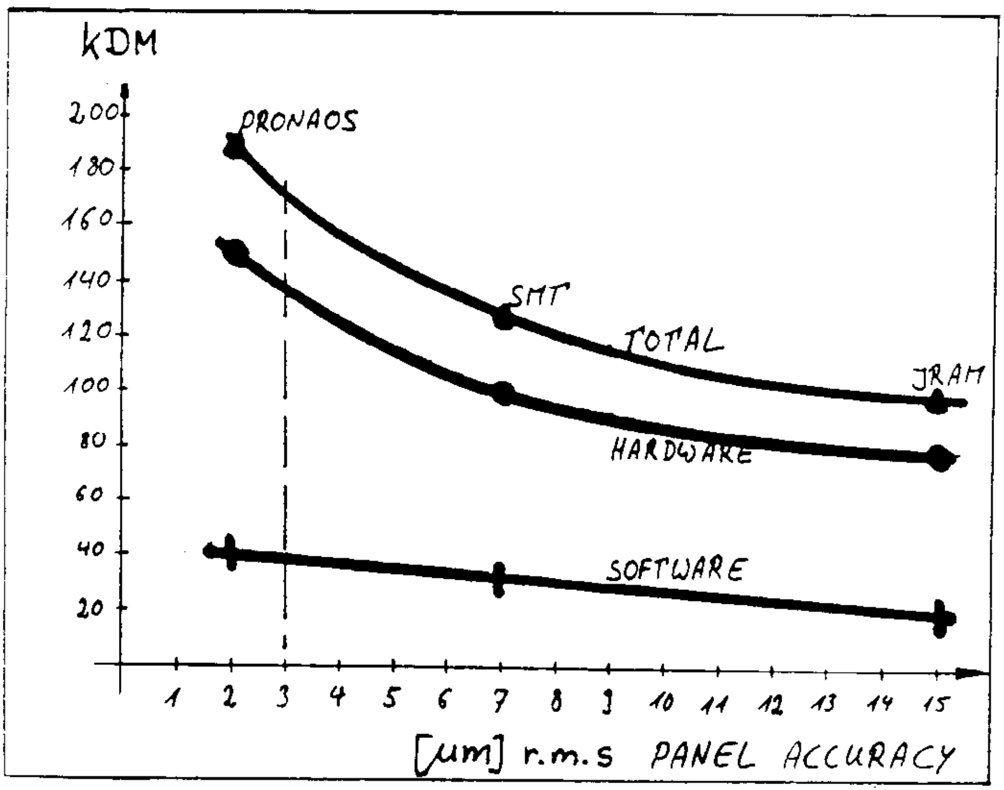


Fig. 4.2 Price of jigs and tools

For the specified SAO panels with 6 μm rms goal total tooling costs are

DM 140.000 per panel type

4.3 Manufacturing

For high accuracy panels high accurate molds are necessary. Steel molds as well as glass molds can be made with accuracies of 2 to 5 µm, which is necessary for the required panel accuracy. The surface roughness must be below 0,5 µm, which is also possible for both materials, but steel molds must be nickel-coated and polished. Fig. 4.1shows curves for wellknown costs given by experience.

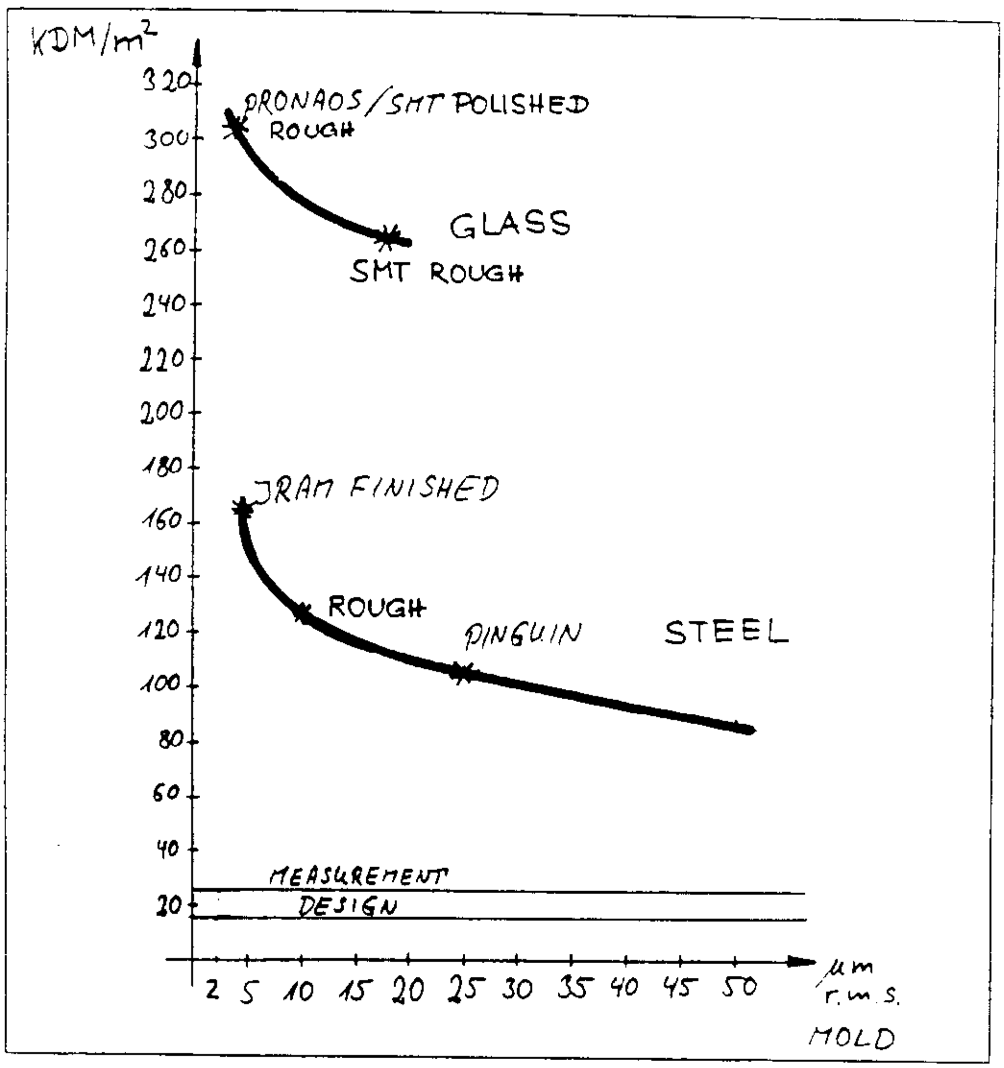


Fig. 4.1 Price per mold area

PANEL COST

Fig. 4.3 shows costs for different panel systems. for the SAO array only panel with

> Cfrp skins and
> aluminium hexagonal core

is possible. The accuracy goal of 6 µm rms leads to panel cost of 16.000 DM/m²

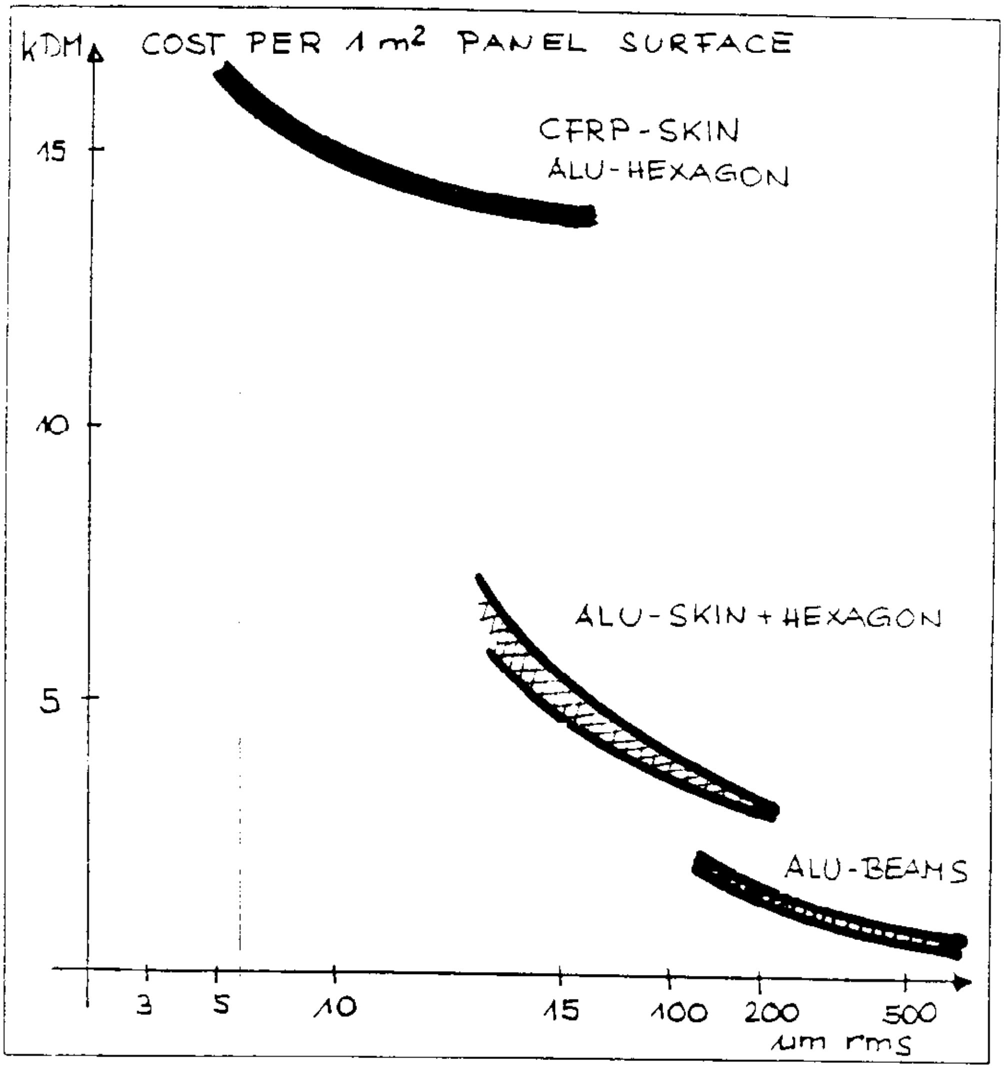


Fig. 4.3 Panel cost per area

These costs have to be muliplied with the area price factor given by the real panel area (Fig. 4.4)

For SAO with a 2 ring reflector with 12 panels, each the panel area are

- panel 1 0,8 m²
- panel 2 1,4 m²

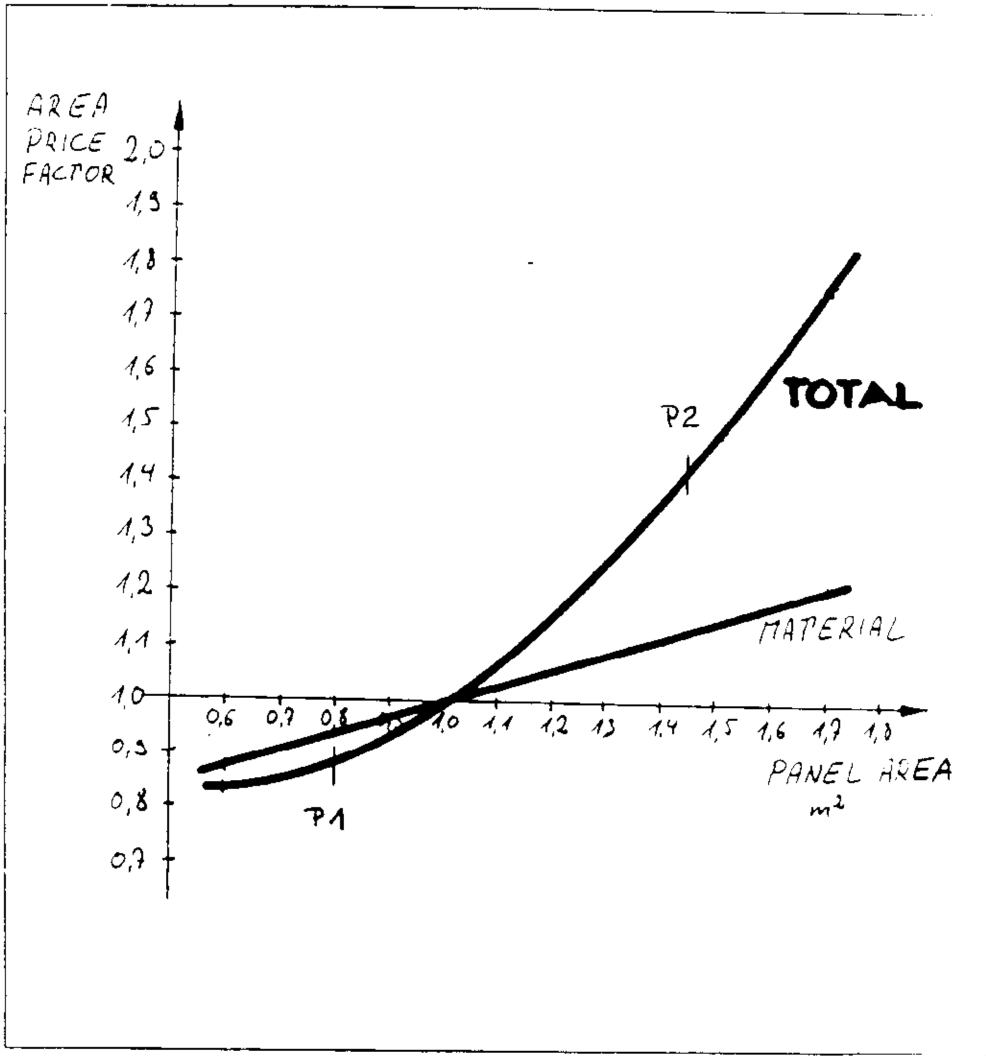


Fig. 4.4 Area factor

This results with cost factors of

0,85 for panel 1
1,45 for panel 2

to total panel costs of

DM 500.000,-- per dish.

BACK UP STRUCTURE

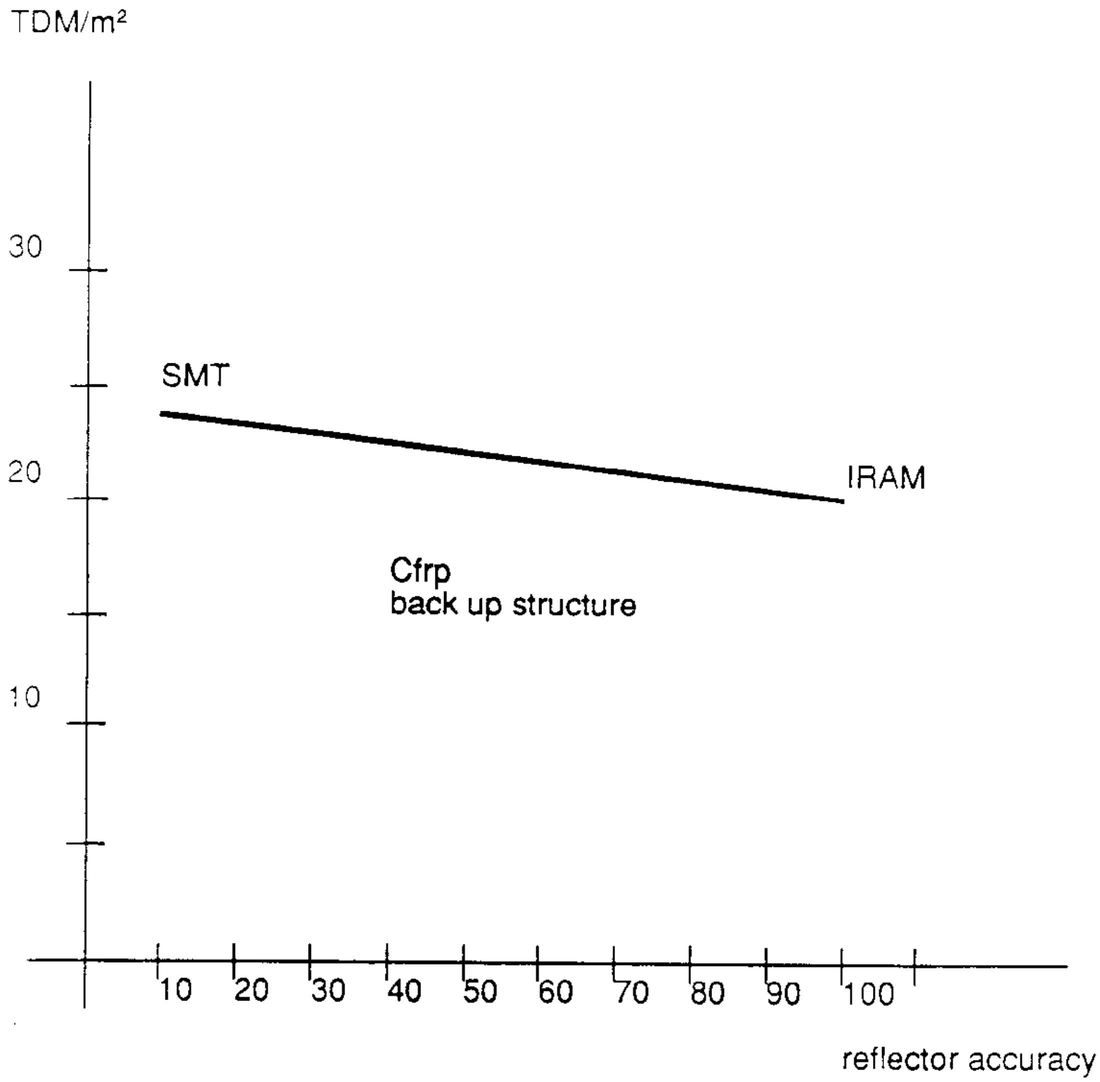
Analysis of the structure costs show no severe influence of reflector accuracy on the price for the only two realized Cfrp reflectors. Therefore approximately

25.000 DM/m² reflector surface

have to be estimated for a standard Cfrp structure. This results in app.

700.000 DM for the SAO structure.

Using new segmented designs without special nodes this price may be reduced as app. 25 percent are node and flange costs.



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SUPPLEMENTARY COSTS

Further costs for several parts are necessary

Electromechanical fixations

DM 500 per piece

for SAO with 24 panels and 4 fixations each

these summs up to

DM 90.000 including wiring system.

Central hub

This citical item is difficult to estimate, because there a steel central hub may be also possible. Therefore only very rough costs can be given for

steel:	40.000 DM
Cfrp:	100.00 DM

Deicing

Deicing systems can be assumed to app. 40 TDM per reflector.

Assembly

Assembly of reflector with a quick assembly design in segments is assumed for 2 weeks with 4 persons, resulting in app. 70.000 DM.

4.5 Operations

Operation cost are directly related to the site, the final surface coating and the possibilities for protection.

For such high quality antennae one should foresee each six months a one day check and each year a more detailed check of app. 2 days.

If no deicing system is installed no operational costs will occur.

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4.6 Summary

The budgetary cost estimates of chapter 4 are based on the todays price rates and must be extrapolated with app. 5 percent per year for the realistic manufacturing time.

As a summary following costs are available

Definition study	DM	250.000
Design	DM	800.000
Manufacturing installation		
molds (2 glass)	DM	750.000
tool	DM	280.000
Non recurring costs	DM	2.080.000

Recurring costs per telescope:

Panels	DM	500.000
Back up structure	DM	400.000
Actuators	DM	90.000
Central hub	DM	100.000
Assembly	DM	70.000
Reflector	DM	1.160.000

With increasing number of telesopes this figure may change.

Recent result from post program cost analysis show that development cost similar to reflector cost and also tooling cost similar to reflector costs. This is shown

development	1.050 KDM
tooling	1.030 KDM
telescope	1.160 KDM

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5. Conclusion

After all preliminary assumptions and estimations it is possible to design and built a submillimeter radiotelescope array with the specified accuracy.

The system should consist of:

- Cfrp back up structure
- panels with Cfrp skins and aluminium hexagonal core
- 2 rings of panels
- 12 panels per ring

The cost for such a reflector would be

2.080.000 DM nor recurring costs

1.160.000 DM per reflector dish

For the next phase immediate studies are necessary for:

- development of surface coating (preferred INVAR-foil coating)
- analysis of back up structuro with a comparison Cfrp and steel
- analysis of panel type 2
- manufacturing of a Cfrp panel with INVAR-foil for long time exposure

These 4 work packages are part of the phase "Definition Study".

SUMMARY OF RECOMMENDATIONS

- 2-RING SYSTEM
- 12 SEGMENTS PER RING
- 4 FIXATION POINTS
- CFRP-SKIN
- ALUMINIUM HEXAGONAL CORE
- INVAR COATING
- ELECTROMECHANICAL ADJUSTMENTS
- OPEN TRUSSWORK STRUCTURE
- NO TEMPERATURE CONTROL SYSTEM

T.B.D.-ISSUES

- STRUCTURE DESIGN AND MATERIAL
- PANEL THICKNESS

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PROPOSALS FOR NEXT PHASE STUDIES

- VERIFICATION OF OUTER PANEL WITH FEM
    * TEMPERATURE
    * WIND LOAD

- MANUFACTURING OF A TEST PANEL ON IRAM MOLD
    * CFRP SKIN/ALU-CORE
    * INVAR FOIL SURFACE

- PANEL TEST
    * HOLOGRAPHY WITH ΔT
    * NORMAL ENVIRONMENT (MUNICH) WITH AGEING EFFECT

- ANALYSIS OF PROPOSED STRUCTURAL ELEMENT
    * STEEL/CFRP-COMPARISON
    * RMS OF FIXATION POINTS